APPENDIX G

Vessel Wakes Technical Memorandum

(Note: This memorandum was prepared prior to development of the DEIS. Subsequent analysis resulted in some minor changes in conclusions, but overall methods and analysis are the same.)

Peratrovich, Nottingham, & Drage, Inc.
engineering consultants

DRAFT Technical Memorandum

Vessel Wakes

Glacier Bay Environmental Impact Statement
Glacier Bay National Park And Preserve, Alaska

November 2002

Prepared By
Peratrovich, Nottingham & Drage, Inc.
1506 West 36th Avenue
Anchorage, Alaska 99503

Prepared For
Ecology and Environment, Inc.
840 "K' Street,
Anchorage, Alaska 99501

PN&D Project No. 02056

Table of Contents

Tables

Figures

Plates

Attachments

1 INTRODUCTION

The purpose of this technical memorandum is to describe the nature of vessel generated waves, referred to as wakes, in Glacier Bay National Park and Preserve, Gustavus, Alaska. The analysis compares the effects of vessel generated surface waves to the effect of natural wind generated surface waves. This analysis was applied to selected sites on the Glacier Bay proper shoreline. The reason for the analysis is to identify where vessel wakes could cause adverse effects to the resources and/or users of the park. This information will be used as one element in determining the appropriate number of vessels and vessel operating requirements in the park. The technical memorandum presents a method to evaluate the different physical effects caused by wakes for each respective alternative in the Environmental Impact Statement on Vessel Quotas and Operating Requirements (EIS). Other effects of vessel generated waves on park users and animal inhabitants of Glacier Bay proper are discussed in other sections of the Environmental Impact Statement. Many terms used in this memorandum have specific meaning in coastal engineering. Please see section 6 for definitions.

2 EXECUTIVE SUMMARY

An extensive literature search was conducted to identify any existing evaluation models that were directly applicable to this project. None were found so the theory behind several existing models was utilized in developing the models used for this study. The process used to determine the sites was to identify where vessels travel within 2,000 feet of the shoreline. This distance was based on research and the accuracy of the vessel traffic data. The next step was to conduct a wind analysis and derive the wave climatology for each site. The wave climatology provides the energy imparted to the site over a one-year period due to natural wind waves. An energy index was calculated for each site by comparing the energy imparted by vessel wakes to natural wind waves. This index makes it possible to discern the effect due to natural wind wave energy from the effect due to vessel wakes despite differences in wind energy at all sites. The potential erodability of the site was evaluated by examining existing data on substrate size and beach slope. The site was assigned an overall erosion potential based on the site erosion potential due to substrate and the vessel wake energy index.

3 BACKGROUND

This section provides the theoretical basis for the analysis of waves. It is intended to provide the reader with an understanding of the various wave models available, which model(s) were used, and how those models were used in the evaluation of waves and wakes on the shoreline of Glacier Bay proper.

3.1 BASIC ASSUMPTIONS AND INFORMATION

There are many causes of waves across a water body. These include tides, wind, tsunamis, and vessels. The technical memorandum evaluates two generators of waves, wind and vessels.

Wave energy is a quantifiable parameter and is equal to the ability of the wave to do work on the shoreline. The energy that a wave contains determines if and how much effect the wave can have on a shoreline. The energy contained in a wave that can act on a shoreline can be measured many ways. For this memorandum, the wave height is the measure for the energy contained within a wave.

A site visit to Glacier Bay revealed no observable signs of erosion or effects of vessel wakes on the shoreline. However, wave energy from vessels could have an impact over time which is not readily observable.

3.2 WIND WAVE CLIMATOLOGY

The wind wave climate is a description of the waves that are a result of the wind and is similar to describing the general weather pattern for an area. It provides wave heights and periods of typical waves. Identifying the wind wave climate at each site provides a way to analyze the effects of waves on that site. Wind induced waves are natural, or background, levels of energy that interact with the shoreline and the energy contained in a wave may act to change the shoreline.

There are several pieces of information necessary to analyze the natural wind wave climate in the park or any other location. The most important is the wind conditions. The wind speed, duration, and direction need to be measured over a period of time, preferable many years. After evaluating the wind speed, duration, and direction, the size of the natural waves can be determined. The orientation of the open water body plus its size, fetch, and depth determines the size of waves that can be generated by the wind. The typical period of a wind-generated wave in Glacier Bay proper is 1-3 seconds.

3.3 VESSEL WAKE CLIMATOLOGY

Vessels can generate two types of waves, surface and internal waves. Large vessels generate waves that generally affect the top 40 feet of the water column for the largest vessels in Glacier Bay proper. Smaller vessels' effect will be shallower. The first type of wave is surface waves. Surface waves are visible on the surface of the water body. These surface waves have the potential to affect other boaters and the shoreline environment. Surface waves would not be expected to cause mixing of nutrients in the water column. The second type of wave, internal waves, is created by vessels under specific conditions and is capable of causing mixing in the water column. Internal waves are density dependent, which means that there must be stratification in the water column that the vessel directly affects. Internal waves do not act on the shoreline and will not be discussed further in this technical memorandum.

The vessel wake climate is the effect of vessel operation on the waterway. The vessel wake climate is compared to the wind wave climate to analyze how vessel wakes affect the shoreline in excess of natural processes. Various parameters including the vessel's hull shape and displacement, and the distance to where the wave energy is no longer capable of changing the coastline were looked at to determine the size and number of vessel wakes to strike each site. The vessel wake climate pictured in Figure 1 is not capable of affecting the coastline because it is too far away from the shoreline.

FIGURE 1 PASSING BOAT'S WAKE.

3.3.1 Literature Review and Discussion of Models

The literature on vessel wave generation describes models with widely varying inputs and even more widely varying outputs. Models presented by Sorenson (1989), Blaauw et al (1983) and PIANC (1987) were analyzed to determine their applicability to Glacier Bay proper conditions. Examples of their outputs are in Attachment "Wave generation model calculations". No models were found to be directly applicable to this evaluation but the models do provide the basis for the assumptions made in analyzing the available information. A discussion of the models for wave generation and how a shoreline is affected by waves is presented here.

Generation of Surface Waves by Vessels

Vessels displace water in their passage and generate waves on the surface. This phenomenon is directly related to the water resistance encountered by the vessel due to its speed. Vessels generate surface waves in two waveforms: diverging wakes and transverse wakes (Figure 2). The crests of these waves converge at a "cusp line" where their superposition causes maximum amplitude. This means that the wake will be highest at the cusp line due to the addition of the transverse and diverging wakes. Theory and experiments indicate that the angle of the cusp line range from 19 to 22 degrees off the ship track line. The ship track is the route that a particular vessel takes on a specific trip. The energy imparted by the vessel to the water spreads laterally along the lengthening crest lines with correspondingly reduced wave height (Sorenson 1973).

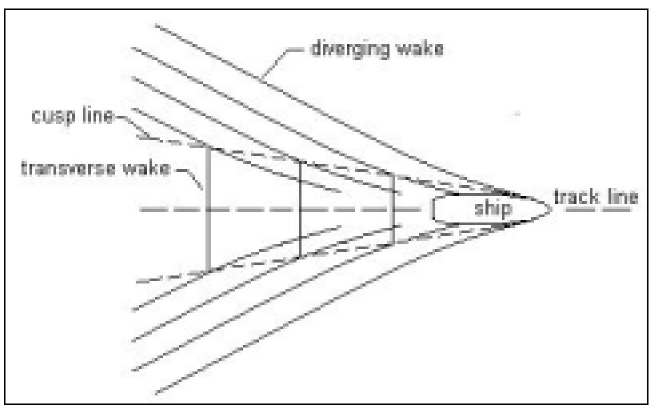


FIGURE 2 PATTERN OF VESSEL-GENERATED WAVES.

The relationship of the vessel speed to the water depth determines the behavior of the wake. A vessel traveling at the same speed through areas with different water depths will produce different wakes. The Froude Number, F, is an accepted measure to define this relationship, defined as

$$F = \frac{V}{\sqrt{gd}}$$, **where** **Equation 1**

V = the vessel speed through the water,
g = acceleration of gravity (32.2 ft/sec2 or 9.81 m/sec2), and
d = water depth.

The transverse wake is longer than the diverging wake, in terms of the horizontal distance between adjacent wave crests, and therefore is first affected by shallow water. When F exceeds 0.6 to 0.7, the transverse wake is transformed through interaction with the bottom and its propagation speed is constrained. This means that transverse wakes are more quickly dissipated and less likely to reach a shore or any great distance from the vessel when the water body is shallow. Waves cannot exceed a propagation speed of $\sqrt{gd}$, so no transverse waves are possible when F is greater than one. Only diverging wakes are generated when vessels, like small powerboats on plane or larger high-speed catamaran excursion boats, are at higher speeds. Diverging waves have shorter wavelengths than transverse wakes and are less prone to water depth effects. Their propagation speed, C, is predicted by:

$C = V \cos\theta$, where **Equation 2**

$\cos\theta$ = the trigonometric cosine of the angle of wave propagation to the ship's track line.

V = the vessel speed through the water

The pattern of a group of diverging waves from a single ship passage experienced at some point away from the track line is typically 15 waves with increasing wave heights to a central maximum height, as illustrated in Figure **3** (Sorensen 1973 and 1989, Weggel and Sorensen 1986, and Maynard 2001). The maximum height of the wake is initially a function of ship speed, displacement, and underwater shape. The wake height decreases with distance from the track line.

FIGURE 3 GROUP PATTERN OF 15-20 WAVES. THE WAVES ARE GENERATED BY A SINGLE VESSEL PASSAGE, EXPERIENCED AT A POINT ON THE WATER OFFSET FROM THE TRACK LINE.

Predictions of maximum wave height at a given distance from the track line are based on empirical findings. Weggel and Sorensen (1986) predict maximum wave height, H_m, at track offset distance, x, on the basis of F, water depth, d, and the cube root of ship displacement, $V^{1/3}$. See pages 4, 5 and 6 of Attachment "Wave generation model calculations" for details of the formulation. Figure 4 illustrates an example application for a cruise ship. Note that the predicted maximum wave height decreases as the wake travels farther from the vessel that produced the wake. This equation is conservative in comparison to other similar formulations and measurements (Blaauw et al 1984, PIANC 1987, Sorensen 1989, Hüsig et al 2000, and Veri-Tech 2002).

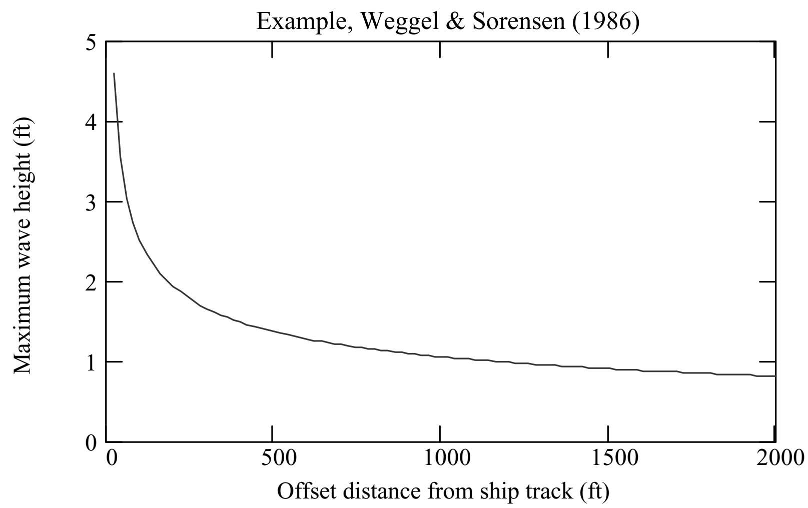


FIGURE 4 EXAMPLE APPLICATION OF WEGGEL AND SORENSEN (1986). GIVEN A SHIP OF 1000 TONS DISPLACEMENT WITH A SPEED OF 15 KNOTS THROUGH THE WATER IN 100 FATHOMS DEPTH. THE WAKE IS PREDICTED TO PROPAGATE AT C = 12.2 KNOTS WITH AN ANGLE θ = 35.3 DEGREES TO THE SHIP TRACK AND TO HAVE A PERIOD T = 4.0 SECONDS AND WAVELENGTH L = 83.4 FT. WAVE HEIGHTS BEFORE AND AFTER THE MAXIMUM WILL BE DIMINISHED AS SHOWN IN FIGURE 3.

Table 1 provides the maximum wave height generated by a series of vessels at a speed of 10 knots, as presented in Sorensen (1973). Sorensen's measurements demonstrate that vessels of varying sizes all had wakes with maximum wave heights of less than 1-foot at a distance of 500 feet from the sailing line. Similar findings were reported in a study which measured vessel wakes on the Kenai River and Johnson Lake (Maynord 2001). In this study Maynord looked at the vessel wakes of 16 to 20-foot long boats of various hull shapes and beams. He found that these vessels generated maximum waves at speeds of approximately 8-knots. The waves were less than one foot measured between 30 and 50 feet from the track line. Although the wave height dropped off rapidly with distance from the track line, the wave's periods remained constant.

TABLE 1 MAXIMUM WAVE AMPLITUDES GENERATED BY A SERIES OF VESSELS AT A SPEED OF 10 KNOTS AS PRESENTED BY SORENSEN (1973).

Vessel	Length ft	Beam ft	Draft ft	Displacement tons	Distance from sailing line 100 ft Height ft	500 ft Height ft
Cabin Cruiser	23	8.25	1.7	3	1.1	0.8
Coast Guard Cutter	40	10	3.5	10	1.6	1
Tugboat	45	13	6	29	1.6	0.9
Fishing boat	64	12.8	3	35	1.8	0.7
Fireboat	100	28	10.5	343	1.6	1

3.4 DESIGN WAKE ASSUMPTIONS

- Design Wake height is 1 foot. This is the maximum wave height expected for any of the vessels permitted in Glacier Bay proper and therefore is protective of the coastline.
- All vessels within 2,000 feet of the shoreline will have a design wake of 1-foot. (See "Vessel Track Analysis Methodology" for information on the selection of 2,000 feet from the shoreline for analysis purposes).
- Vessels generate 15 wake waves. This is the maximum number of waves that will intercept the shoreline at any one point from a passing vessel.
- All wake energy is assumed to be directed perpendicular to the shore.

4 GLACIER BAY PROPER ANALYSIS METHODOLOGY

4.1 METHODOLOGY FOR CONDUCTING WAKE ANALYSIS OF GLACIER BAY PROPER

PN&D analyzed the collected data and chose specific sites that will require detailed evaluation. This was done by:

- evaluating vessel track data for proximity to shoreline to determine the number of vessels that come within 2,000 feet of the shoreline for the energy index calculation

- evaluating Gustavus, Alaska wind data to determine the natural wind patterns including strength (wind speed) and direction
- examination of the physical features of Glacier Bay proper to determine the physical restrictions and limitations in wave development,
- evaluating the fetch geometries of the chosen sites to determine the amount of wind wave energy that will assault the site and compare that to the vessel wake energy at the same site, and
- evaluation of material size at beaches to determine risk of erosion.

4.2 GLACIER BAY PROPERPHYSICAL FEATURES

The mouth of Glacier Bay proper is located near Gustavus, Alaska, which is 50 miles due west of Juneau, Alaska. Glacier Bay proper (Plate 1) is approximately 60 miles long and consists of a 4-mile wide entrance narrows, Sitakaday Narrows, which opens up into an approximately 12-mile wide main body. North of the main body, the East Arm creates a north-south fetch of approximately 55miles. The West Arm also creates a maximum fetch of 55 miles, oriented at 140 degrees. Fetches are distances over which waves are generated when sustained winds blow. These long fetches, over deep waters of Glacier Bay proper, create a wave climate similar to the open sea. Water depths in mid-channel range from 200 feet in Sitakaday Narrows to 1,400 feet in the upper West Arm. Glacier Bay proper also contains many protected waterways in various orientations and the wave climate will differ substantially from the open areas. Analysis with restricted fetches (narrow channels) applies to the waves generated in these protected waterways.

Tidal currents and waves are major influences over the shape of beaches. This is a relatively new method of influence in Glacier Bay proper due to the long period of glacial ice coverage. Glacier Bay proper is an example of a secondary coast, in that terrestrial forces, in this case, glacial activity, formed it. The tidal range in Glacier Bay proper is large at approximately 24 feet. Tidal currents act on the shoreline primarily as long shore transport. In addition, wave action acts both perpendicular to the shore and parallel to the shore; something that was absent until recently due to glacial ice covering the bay.

4.3 SITE VISIT

PN&D conducted a site visit to Glacier Bay proper on June 12, 2002. One of the purposes of the site visit was to observe maximum tides and currents. The site reconnaissance consisted of taking photographs and recording the vessels path using a global positioning system (GPS) unit during an eight hour Spirit of

Adventure Tour Vessel Cruise from Bartlett Cove to Grand Pacific Glacier at the head of the West Arm. The GPS record for the cruise is shown in Plate 1. The vessel positions and speed between waypoints is provided in Attachment "Spirit of Adventure positions and speeds". During the trip around the bay, a negative 2.7-foot (extreme low) tide was observed at approximately 9:30 am. A brown bear was observed foraging at the waterline on the exposed food supply at the extreme low water mark (see concentration of waypoints just north of Tidal Inlet, Plate 1).

The data collected by the GPS during the site visit included vessel track (route) and speed. Vessel track information is necessary to estimate the number of vessels that are close enough to the shore to affect the shoreline. GPS provides a speed relative to the ground; much like a speedometer provides the speed of a car. This does not provide the speed of the vessel in relation to the water when there are currents. To identify the speed of Spirit of Adventure in relation to the water, PN&D used coastal prediction tables available at NOAA/OPS online. The maximum ebb current was 5.2 knots west of Beardslee Island and the maximum flood current was 6.1 knots for the day of the site visit. These values corresponded with the 4-knot flood current observed by the ship captain at 2:15 pm, which should have been the time of maximum flood current adjusted to that location. By using the GPS record made during the cruise, Spirit of Adventure speed relative to the water at any time can be inferred using its GPS speed log (speed relative to the ground) and tidal currents predictions for each location. The GPS record also provides the distance from the shore that the vessel traveled. This is necessary information to determine which sites to investigate further.

FIGURE 5 DAWN PRINCESS, CRUISE SHIP CLASS

The investigators observed that the cruise ship Swan Princess (Figure 5) appeared to be traveling at top speed up Glacier Bay proper at 1pm on June 12, and appeared to have generated a wake of less than 1 foot height at a distance of 2,000 feet, when Spirit of Adventure crossed its wake. The period of the wake was between 1 and 2 seconds. The period and distance were estimated by timing the sound and motion induced in the video recording of the wake crossing.

4.3.1 Ship Captains Interview

One of the purposes of the trip was to observe the wake produced by catamaran tour vessels, such as Spirit of Adventure. This vessel has very desirable characteristics for a tour vessel because it accelerates rapidly and produces minimum wake and noise. The maximum wake, according to Spirit of Adventure Captain Kanoi Taylor, occurs when the boat is at the speed of 12 to13 knots relative to the water. The maximum water height generated by Spirit of Adventure is not in the form of a wave. The frothy convergence centered behind the stern quickly dissipates energy without contributing energy to formation of waves. See Figure 6, Spirit of Adventure wake. This type of wake is advantageous for a vessel which makes frequent stops along beaches, as waves from the departure wake are minimized.

FIGURE 6 SPIRIT OF ADVENTURE WAKE

4.4 WIND WAVE ANALYSIS METHODOLOGY

The wind wave analysis calculates the natural wind wave heights and periods for sites in Glacier Bay proper. Site-specific wind measurements are unavailable for Glacier Bay; however it is available for Gustavus Airport, Alaska. Several coastal cities in southeast Alaska have first order stations, including Juneau (1987-1999), Sitka (March-December 1999), Ketchikan (March-December 1999), and Cordova (December 1999). Wind summaries and wind roses for Juneau, Ketchikan, Sitka and Cordova are presented in Attachment "Wind summaries for Sitka, Ketchikan, Juneau, and Cordova (1987-1999)". Weather data collection stations have different ratings based on collection methods and accuracy standards with first order stations having the most reliable data. Plate 2 compares Gustavus to its nearest first order station and demonstrates that the wind patterns in Gustavus are similar to Juneau and sufficient for this evaluation. Therefore, data from the Gustavus Airport from 1987 to 2002 was used as the baseline data for the Glacier Bay wind analysis. The airport anemometer in Gustavus is on a flat, sparsely treed delta and is likely to share its wind climate with Glacier Bay proper. National Climate Data Center provided raw wind data for Gustavus.

As in all of southeast Alaska, wind directions induced by large-scale weather patterns prevail along the main channels of the bay. The dominant NW-SE winds at Gustavus (Plate 2), for example, have a similar speed distribution to N-S prevailing winds in the main channel of the lower bay (Plate 1). Similarly, the distributions of wind speeds in the prevailing directions at Glacier Bay proper and Gustavus are expected to be similar to the speed distribution in the prevailing directions at Juneau, 50 miles east, as seen in Plate 5. A pattern of wind speeds and directions in selected parts of Glacier Bay proper was constructed following this above logic.

For the wave analysis, below, PN&D used the Gustavus wind rose to combine related sectors of winds. This is done to determine the directions to use for the wave analysis. Five categories appear to be most significant and winds from combining related sectors are shown in Plate 3. The related groups were assigned the values of 50°, 130°, 200°, 260° and 340°.

4.4.1 Fetch Restrictions and Wind Duration Analysis Methodology

Wave analysis requires predicting the height and period of the waves. The length of the fetch, duration and intensity of wind determine the height and period of the waves. Glacier Bay proper has both open fetch areas and restricted fetch areas. In open areas, like the midsection of the main body of water, the fetch is less important than the duration of a particular wind event in generating waves. When this condition exists, the wave growth is said to be duration limited. In a narrow area, like protected inlets and near protecting islands, wave growth will be fetch limited. There is not sufficient fetch length (depending on the direction of the particular wind) in some parts of Glacier Bay proper to generate large waves even if the wind blows strongly for a long time.

In the wave analysis, fetch restrictions were modeled using CEDAS (Veritech, Inc) wind generated wave growth model. Deep water wave growth was used since $d/L>0.7$ for wind waves in Glacier Bay proper. Glacier Bay proper has deep water waves, which means the wave energy does not interact with the bottom. This is similar to the ocean. For a diagram showing application in restricted fetches see Attachment "Technical References", Aces Technical Reference, pages 8 and 9.

The wind duration used for the wave growth model was one hour. This assumption will predict smaller waves than would actually exist during wind events as a typical storm event lasts longer than one hour. A wind event is a period of sustained wind in both speed and direction. This is a conservative assumption from this discussion because the analysis will be biased towards the vessel wakes causing an effect.

4.4.2 Wave Analysis Methodology

The wave analysis includes information from the weather stations and the vessel track information. The information from the weather stations is used to create the natural wind wave climate at each site. The vessel track information is used with the vessel wave design height to create the vessel wave climate at each site. The energy, or ability to do work, of the two climates is compared against each other in the energy index. The number of waves that strike the shore, whether it is a storm or vessel passing, is one measure of the amount of energy in a single event.

According to the Airy (linear wave) theory, if all waves are propagated in the same direction, the total energy for each wave is:

To get the total energy, we multiply the energy per wave by the number of waves. In this report, it is convenient for comparison purposes to define the energy index, N, for a particular coastal site. N is the cumulative energy of the design height (one foot) vessel waves to strike the shore in a year divided by the cumulative energy of wind-generated waves to strike the same shore in a year.

Assumed Wave Height

The approach used for this technical memorandum is to select a conservative wave height based on the vessels which are permitted in the bay and use this height for all calculations. This will provide an increased safety factor in calculating the energy contained within a vessel wake. The conservative wave height value provides a worst-case scenario as this is the maximum wave height expected to be produced by any of the vessels permitted to enter Glacier Bay proper. Further justification of this approach is given at II-7-61, Coastal Engineering Manual (30 Sep 96), see Attachment "Technical References".

Vessel Track Analysis Methodology

Vessel traffic information is required to determine the number of vessel waves at any site. PN&D used the track logged during the site visit on June 12, 2002 and the vessel tracks provided by NPS in order to determine the number of vessel waves. During the site visit on the Spirit of Adventure, this vessel appeared to be traveling closer to shore than any other vessel observed during the trip. According to the GPS record, the Spirit of Adventure maintained an average distance of approximately 1,000 feet when it was closest to shore.

Vessel track data provided by NPS contains shape file data for cruise vessels, tour vessels and charter vessels. There was no information for private vessels. The vessel track data set was used to predict the number of vessels that passed within 2,000 feet of the shore. The tracks within 2,000 feet of the coastline were counted. The analysis uses 2,000 feet because the literature indicates that wakes from vessels are found to have attenuated to approximately 1-foot at a distance of 1,000 feet from the vessels track. The 2,000-foot distance provides an acceptable margin of error and is protective of the coastline against erosion. It is important to note that the NPS stated that their track data is only accurate to ±3,000 feet. NPS track data provides the only information available with which to make a prediction on vessel traffic patterns. Plate 4 Glacier Bay vessel traffic is an example of one of the vessel track datasets from NPS.

Wave and Wake Energy Analysis Methodology

To complete the shoreline effect analysis for Glacier Bay proper, the energy levels for wind-induced waves and vessel wakes are divided to give a comparison index. The following assumptions were made:

- A design vessel wake represented all vessel wakes at each shore site.
- This design vessel wake is conservative as most vessel wakes will have less energy than the design wake.
- The design boat wake maximum height is 1-foot.

- 100% of the vessel wake energy is directed at the shore.
- Wind duration for a storm event is set at 1 hour.

A design boat wake was chosen to represent every vessel wake because reliable statistical information about each particular class of vessels wakes is not available and the vessel wake attenuation through the water has a significant effect on its energy at the shore site. The 1-foot design wake is conservative and biased towards showing an affect on the shoreline. The wind duration for wind-induced waves is conservative as storms typically last longer than 1-hour.

4.4.3 Site Selection for Analysis

Energy levels were generated at 22 study areas (see Figure 9). Details of the selected sites are shown in Attachment "Areas identified for detailed study". These areas were selected by analyzing vessel track information as provided above.

An energy index value (N value) was generated for each of the 22 sites, and the sites were divided into the following categories to compare the ability of vessel-generated waves against natural conditions. This does not consider the substrate material so it is not the effects analysis.

- High – if the energy of the vessel waves is of the same order of magnitude as the wind waves (1/1). This means that all the vessel wake energy over the year has the same amount or more energy as natural background conditions and is highly likely to change (erode) the coastline.
- Moderate – if the energy of the vessel waves is one-tenth of the energy of the wind waves. This means that all the vessel wake energy over the year has one-tenth (1/10) the amount of energy as a natural background conditions and is moderately likely to change (erode) the coastline.
- Minor – if the energy of the vessel waves is one-hundredth of the energy of the wind waves. This means that all the vessel wake energy over the year has one-hundredth (1/100) the amount of energy as a natural background conditions and has a low likelihood of changing (eroding) the coastline.
- Negligible – if the energy of the vessel waves in one-thousandth of the energy of the wind waves. This means that all the vessel wake energy over the year has one-thousandth (1/1000) the amount of energy as a natural background conditions and is highly unlikely to change (erode) the coastline.

The period chosen for the evaluation is one year. This allows for the use of a full year of wind data. Any shorter period would not correctly interpret cumulative effects of wind waves. A longer period would be necessary to correctly predict the effect of climate cycles, for example El Nino. The vessel analysis evaluates a single permit-required season, which generally runs from June through October.

4.4.4 Wind Wave and Vessel Wake Comparison

This section discusses the probability that a design vessel's wake height will exceed a typical summer storm's wave height. This probability is important to discuss because it provides a summary of how strong a wake is compared to a wave. The probability varies from site to site and from beach to beach due to different angles to the wind and the fetch length. Wind direction is an important factor in evaluating the natural wind waves because there must be sufficient fetch to create a wave and the wave needs to be nearly perpendicular to the shore for the wave to act on the beach.

Site 11, see plate 4, provides an example of calculating probabilities. Site 11 has two beaches as it includes the shoreline on each side of Tidal Inlet. Beach A is to the northwest of Tidal Inlet and Beach B is to the southeast of Tidal Inlet. For the same wind intensity and direction, the wind waves along Beach B will be higher because the fetches are longer. As discussed above, wind direction was grouped into five related sectors. For Site 11, the only two sectors of concern are 260° and 340°. Table 2 shows the number of observations when a summer (June through August) wind event created a wave of 1-foot or higher. Table 3 shows the probability of a wind event creating a wave that exceeds the 1-foot design height for selected wind speeds and durations. For example, at Beach A, a 14-knot wind blowing for an hour from 340 degrees can be expected to occur one time in 5 summers and will produce waves of the same height as the design vessel wake. As a comparison, a 10-knot wind from the same direction (340 degrees) for two hours would produce the same wind waves. These two scenarios exert the same amount of energy on the beach. The differing fetches account for the differing probabilities between Beach A and Beach B.

TABLE 2 NUMBER OF OBSERVATIONS WHEN WIND WAVES EXCEEDED 1-FOOT FOR SITE 11. LIMITED TO SUMMER OBSERVATIONS (JUNE, JULY AND AUGUST), GUSTAVUS, AK.[1]

Wind Speed In Knots	Number of Observations with Wind Direction 260°	Number of Observations with Wind Direction 340°
16	1	0
15	1	1
14	2	1
13	9	3
12	12	16
11	27	30
10	59	56
9	105	111
8	158	215
7	276	383

TABLE 3 PROBABILITY OF SELECTED WIND SPEEDS AND DURATIONS PRODUCING 1-FOOT WAVES AT SITE 11.[2]

Wind		Beach A			Beach B		
Duration (Hours)	Direction (Degrees)	Wind Speed (Knots)	Probability of exceeding 1-Foot wave (%)	Average Number of times exceeding 1-foot wave	Wind speed* (Knots)	Probability of exceeding 1-Foot wave (%)	Average Number of times exceeding 1-foot wave
1	340	14	0.0087	0.2	13	0.0260	0.6
2	340	10	0.4858	nc[3]	9	0.9630	nc
3	340	8	1.8652	nc	7	3.3226	nc
1	260	16	0.0087	0.2	14	0.0174	0.4
2	260	12	0.1041	nc	11	0.2342	nc
3	260	11	0.2342	nc	9	0.9109	nc

4.4.5 Wind/Wave Model Assumptions

- Design wake assumptions stated above. The design wake represents all vessels, regardless of size and speed, that come within 2,000 feet of the shoreline.
- Wind wave growth event is 1 hour.
- Glacier Bay is a deep-water environment in terms of wind wave growth and characteristics.
- Analysis period is one-year.

[1] Total Observations equal 11,527.
[2] The wind speed and duration shown are required to produce at least 1-foot waves.
[3] NC = Not calculated (duration analysis not performed)

4.5 PHYSICAL ATTRIBUTE DEFINITIONS

The substrate is the size of material present in the tidal zone. Table 4 provides the definition of the various material types and their potential for erosion.

TABLE 4 SUBSTRATE SIZE CHART

Substrate	Material Size	Comparison Size	Erosion Potential
Bedrock	Continuous rock	Continuous rock	Negligible
Boulder	>256 mm	human head size	Minor
Cobble	64-256 mm	Billiard ball to human head	Minor
Pebble	4-64 mm	Pea to billiard ball	Minor
Granule	2-4 mm	BB to pea	Moderate
Coarse sand	1-2 mm	Pinhead to BB	Moderate
Fine sand	0.0625-1 mm	Gritty (sugar/salt) to pinhead	High
Silt	>0.0625 mm	Smooth; forms clumps/balls	High
Shell	4-256 mm shells/fragments	Shells/fragments	Minor

The CoastWalkers database defines the substrate in terms of primary and secondary substrate. The primary substrate is the material size most commonly found at the site. The secondary substrate is the second most common material size and it has at least 10% coverage.

The slope that a beach can maintain is a function of the material size. Generally, large material also has a steep slope and small material has a gentler slope. The slope of beach is important for analysis because this defines how widely the energy is distributed across the beach (see Figure 8).

The erosion potential of a site is a function of the size of material and the amount of energy it receives. Bedrock has negligible erosion potential. Boulders, cobbles, and pebbles have minor erosion potential and require high energy levels to erode. Granules and coarse sand have moderate erosion potential and fine sand and silt have a high erosion potential. The amount of erosion visible for smaller materials depends on recruitment of new materials. A beach could have a very high erosion potential, yet not erode with a storm because it has a strong source (recruitment point) of new materials.

4.6 OVERALL ANALYSIS METHODOLOGY

Each site is assigned an erosion potential based on the site's potential for erosion. Each site is also assigned a rating for the energy index, which indicates the amount of energy imparted on the site by vessel wakes in comparison to the natural wind wave energy. How these two ratings are obtained and calculated is described above.

Reaching an overall potential effect at a site requires evaluation of the erosion potential rating and the energy index (vessel wake potential) rating. The highest, or more severe, rating common to both categories is the overall rating. For example, Site 1 has a high to moderate rating for erosion potential and a vessel wake potential of negligible. This means that the overall potential effect is negligible. What is instructive by showing both the erosion potential and vessel wake potential ratings is that it is clear how a change in vessel usage near a site could change the overall potential effect. Site 1 is susceptible to an increase in erosion should there be an increase in vessel traffic due to the small substrate. Under the current conditions, vessel traffic is limited and therefore does not significantly affect the shoreline at Site 1. In contrast, Site 4 has an overall rating of minor because both the erosion potential and vessel wake potential ratings are minor. An increase in vessel traffic will not affect the overall rating at this site because the substrate is resistant to erosion.

4.6.1 Assumptions

- No compound wakes occur due to two vessels traveling so closely that their wakes become additive.
- The beach material is assumed to be consistent throughout the tidal zone so tide height is not factored into the analysis. The height of the tide is important for other considerations include near shore and intertidal users.

5 GLACIER BAY PROPER ANALYSIS

5.1 INTRODUCTION

As stated above, there is a two-prong approach to analyzing a site for potential affect due to vessel wakes. The first evaluation is the comparison between the natural wind wave climate and the vessel wake climate. This analysis provides an index of how much energy above the natural wind environment that vessel wakes impart on the coastline. The second evaluation is of the substrate present at the site. The amount of energy necessary to affect a shoreline depends on the type and size of material. The analysis is complete when the energy potential from the vessel wakes is considered with the substrate material.

5.2 ANALYSIS EXAMPLE SITES

Two sites were selected to show the analysis process. The first site, Site 20, is in upper Muir Inlet near Stump Cove (Figure 7) and the second site, Site 11, is in the Lower West Arm (see Plate 4).

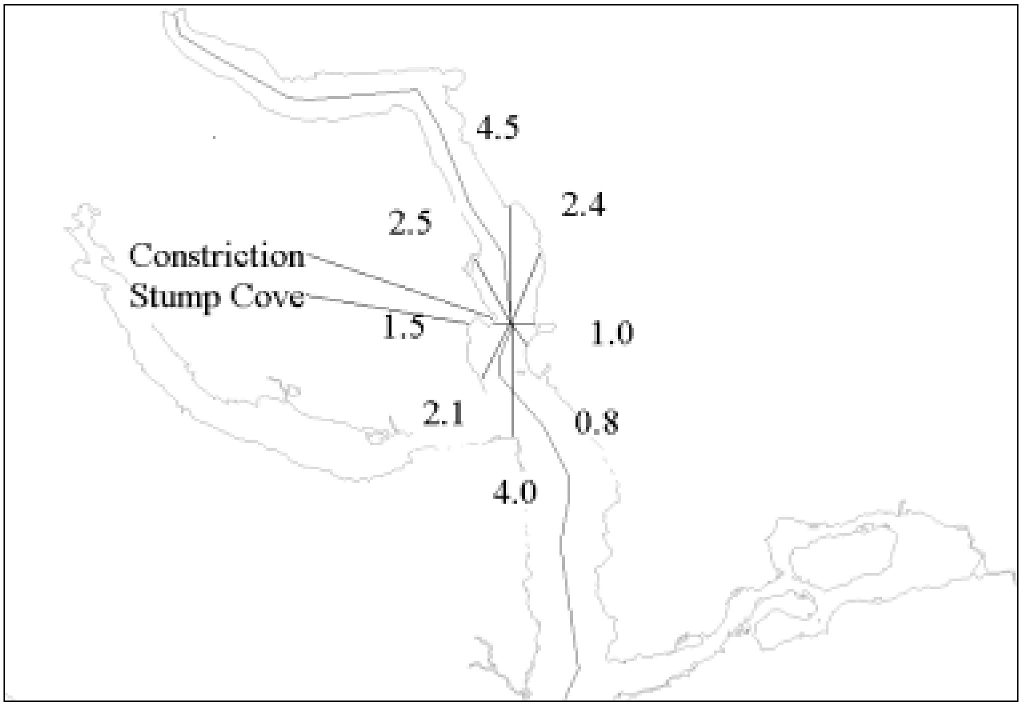


FIGURE 7 FETCH LENGTHS IN MILES IN UPPER MUIR INLET NEAR STUMP COVE, SITE 20.

Site Descriptions

Stump Cove has a narrow and curving channel that is likely to force traffic closer to shore. The Lower West Arm site is moderately well sheltered. The fetch lengths, in miles, near Stump Cove are shown in Figure 7. Site 11 and 20 are representative of the types of areas most likely to be adversely affected by vessel wakes and thus requiring the most attention when evaluating vessel quotas and operating requirements. Due to the size of the vessels and safe vessel traffic management standards, it is assumed that vessels would not travel in the same track at the same time to produce compounded wakes. Additionally, this analysis does not distinguish between the times of day or tidal cycle. The energies calculated are for a square foot of shoreline perpendicular to the shore. The energies due to tide and the part of wave energy which is directed parallel to shore are pictured with the second arrow in Figure 8. Energy parallel to shore is responsible for long shore sediment transport and was not considered in computing the energy index, N.

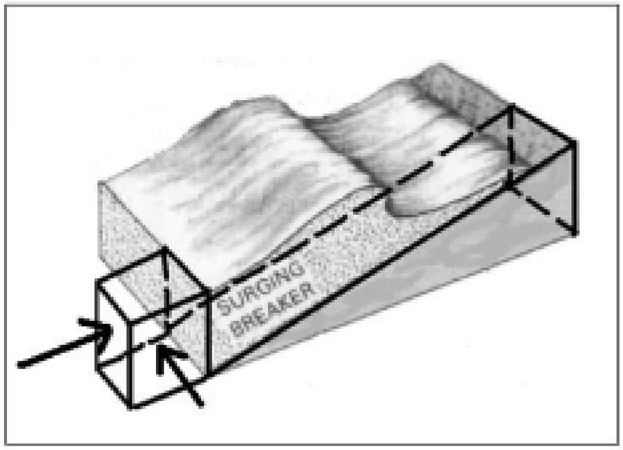


FIGURE 8 WAVE ENERGIES RELATED TO THE SHORE

Wind and Wake Example Analysis

Attachment "Example calculations" provides the calculation of the energy index for the Stump Cove site (Site 20). The example follows all the assumptions listed previously. The Stump Cove site is one of the more sheltered areas in Glacier Bay proper where motorized vessels are permitted. This site experiences little to no vessel traffic according to the NPS vessel track data. With the current vessel traffic, this site has an energy index of N=0.008, which is below the negligible significance level. In other words, vessel wakes impart less than one thousandth (1/1000) the amount of energy on this site than natural wind waves.

The second example analysis is a moderately well sheltered site in the lower West Arm (Site 11). With the current vessel traffic, this site has an energy index of N=0.02, which is minor significance level. In other words, vessel wakes impart less than one tenth (1/10) but more than one hundredth (1/100) the amount of energy on this site than natural wind waves. See Table 5 for a comparison of the two sites.

TABLE 5 VESSEL WAKE AND WIND WAVE ENERGY COMPARISON AT 2 SITES

Site	Vessels		Wind	Energy Index (N)[4]	Significance Level
	# of vessel wakes	Energy	Energy		
Stump Cove (site 20), Beach A	362	112	148,000	0.008	Negligible
Lower West Arm (site 11), Beach A	6,515	2,014	108,000	0.02	Minor

Wave energy at a site is expressed in units of square feet perpendicular to the shore. However, the actual energy transfer takes place on the face of the shore, which is the long rectangular area under the breaker in Figure 8. A steep beach will have a much larger concentration of energy upon its face than a gentler sloping beach as shown in Figure 8. The range of beach slopes in Glacier Bay proper is approximately 1/10 of one degree to 75 degrees. For the range of beach slopes here, there is a range of between 1 and 600 square feet of beach area influenced by the waves. Thus the concentration of energy on the steepest beaches is 600 times the concentration of energy on the gentlest beaches for one given wave climate.

TABLE 6 POTENTIAL AFFECT ON 22 SITES BY VESSEL WAKES WITH CURRENT QUOTAS.

Site	Beach potential[5]	Assigned Site Total potential[6]
1	Negligible	Negligible
2	Minor	Minor
3	Negligible	Negligible
4	Minor	Minor
5	Minor	Minor
	Minor	
6	Negligible	Negligible
7	Negligible	Negligible
	Negligible	
	Negligible	
8	Negligible	Negligible
	Negligible	
9	Negligible	Minor
	Negligible	
	Minor	
10	Negligible	Negligible

[4] Energy Index (N) is equal to the vessel wake energy divided by the wind wave energy.
[5] Each site is divided into one or more beaches. This is due to the different fetches and variations in the shoreline, which affect the waves that can strike the shore.
[6] To be conservative, the highest potential level for a beach is also the total potential.

Site	Beach potential[5]	Assigned Site Total potential[6]
11	Minor Negligible	Minor
12	Minor Minor Negligible	Minor
13	Negligible Negligible	Negligible
14	Negligible Minor Negligible	Minor
15	Minor Minor	Minor
16	Negligible Moderate Moderate	Moderate
17	Minor	Minor
18	Minor Negligible Minor	Minor
19	Negligible Negligible	Negligible
20	Negligible Negligible Negligible	Negligible
21	Negligible	Negligible
22	Minor	Minor

5.3 PHYSICAL ATTRIBUTES OF THE 22 SITES BEING ANALYZED

The vessel wake analyses identified 22 sites where vessels travel close enough to the shoreline to potentially cause change on that shoreline (see Figure 9). This section provides a summary of the physical attributes of the 22 sites identified as presented in the CoastWalkers database. The physical attributes summarized below include the primary substrate, secondary substrate, and the slope. These attributes are important in evaluating the potential for erosion.

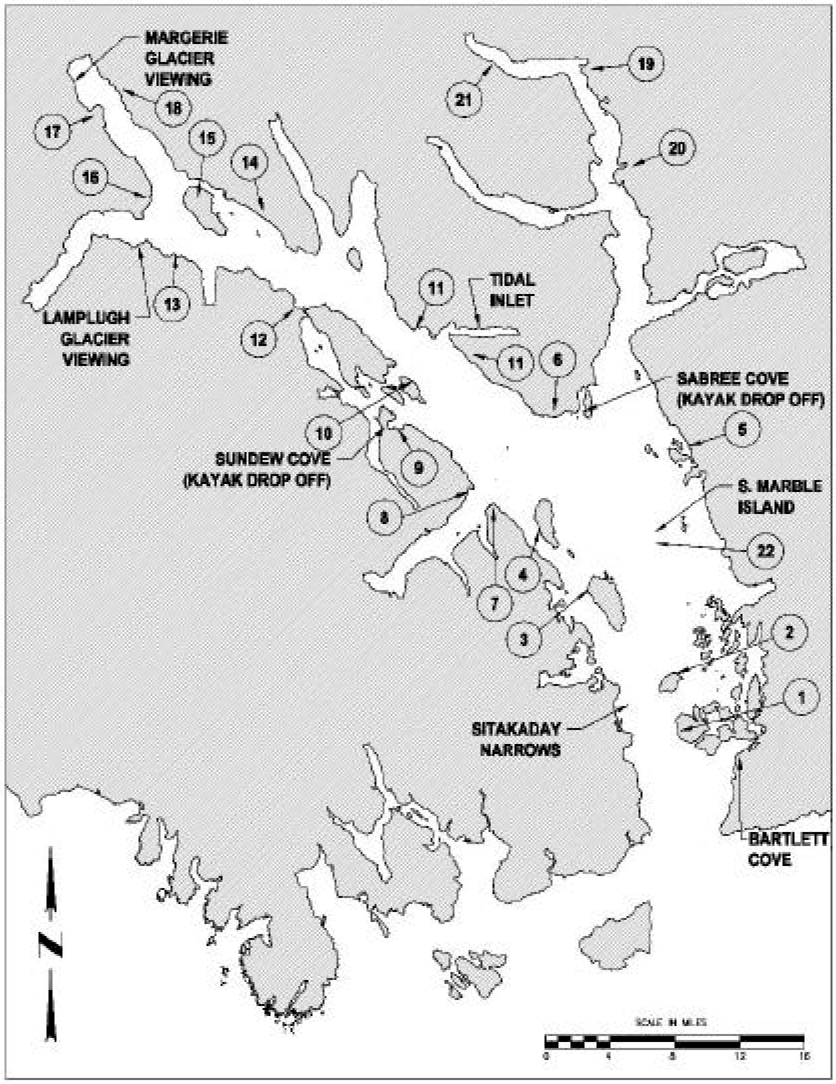


FIGURE 9 SITES SELECTED FOR VESSEL WAKE ANALYSIS.

5.3.1 Physical Attributes of the 22 Sites

The NPS CoastWalker database provides substrate and slope information for each polygon mapped. The polygons are based on changes in substrate material size and the slope. Table 7 provides site information based on the CoastWalker database by summarizing the substrate information for all polygons in the site. See Attachment "CoastWalkers Polygon Table" for a list of the polygons included in each site. The sites have anywhere from eight polygons to 119 polygons representing a single beach in this technical memorandum. The average number of polygons for a single site is approximately 40.

TABLE 7 SUBSTRATE TYPES AND SLOPE FOR EACH SITE.

Site	Primary Substrate	Secondary Substrate	Slope (degrees)	Erosion Potential
1	coarse sand	granule	2.9	High
2	pebble	pebble	5.2	Moderate
3	cobble	cobble	16.4	Minor
4	cobble	boulder	11.8	Minor
5	pebble	pebble	8.8	Moderate
6	pebble	cobble	8.2	Moderate to Minor
7	boulder	cobble	18.0	Minor
8	cobble	cobble	11.5	Minor
9	granule	pebble	7.8	High to Moderate
10	boulder	cobble	13.1	Minor
11	cobble	cobble	16.5	Minor
12	cobble	cobble	13.9	Minor
13	cobble	cobble	16.2	Minor
14	granule	pebble	6.7	High to Moderate
15	cobble	boulder	15.4	Minor
16	boulder	boulder	31.9	Minor
17	boulder	boulder	27.0	Minor
18	pebble	pebble	11.7	Moderate to Minor
19	Not mapped			N/A
20	Granule	granule	8.1	High
21	Not mapped			N/A
22	Not mapped			N/A

Site 1

The average material size for site 1 is coarse sand. The minimum size material is silt and the largest is cobble. The median and mode material size is fine sand. The average secondary substrate size is granule. The minimum size material for secondary substrate is silt and the largest is cobble. The median and mode material size for secondary substrate is pebble. The average slope is 2.9 degrees. The minimum slope is 1 degree and the maximum slope is 5 degrees. The median slope is 2.75 degrees and the mode is 2.5 degrees.

Site 2

The average material size for site 2 is pebble. The minimum size material is granule and the largest is cobble. The median and mode material size is cobble. The average secondary substrate size is pebble. The minimum size material for secondary substrate is pebble and the largest is boulder. The median and mode material size for secondary substrate is pebble. The average slope is 5.2 degrees. The minimum slope is 0 degrees and the maximum slope is 8 degrees. The median slope is 5.75 degrees and the mode is 7 degrees.

Site 3

The average material size for site 3 is cobble. The minimum size material is coarse sand and the largest is bedrock. The median material size is boulder and mode material size is bedrock. The average secondary substrate size is cobble. The minimum size material for secondary substrate is coarse sand and the largest is bedrock. The median and mode material size for secondary substrate is cobble. The average slope is 16.4 degrees. The minimum slope is 4 degrees and the maximum slope is 66 degrees. The median slope is 12 degrees and the mode is 7 degrees.

Site 4

The average material size for site 4 is cobble. The minimum size material is granule and the largest is bedrock. The median and mode material size is pebble. The average secondary substrate size is boulder. The minimum size material for secondary substrate is granule and the largest is bedrock. The median and mode material size for secondary substrate is cobble. The average slope is 11.8 degrees. The minimum slope is 2.5 degrees and the maximum slope is 26 degrees. The median slope is 10 degrees and the mode is 8 degrees.

Site 5

The average material size for site 5 is pebble. The minimum size material is fine sand and the largest is bedrock. The median and mode material size is pebble. The average secondary substrate size is pebble. The minimum size material for secondary substrate is silt and the largest is boulder. The median material size for secondary substrate is pebble and mode material size is cobble. The average slope is 8.8 degrees. The minimum slope is 2.5 degrees and the maximum slope is 21.5 degrees. The median slope is 7.5 degrees and the mode is 12 degrees.

Site 6

The average material size for site 6 is pebble. The minimum size material is silt and the largest is bedrock. The median and mode material size is pebble. The average secondary substrate size is cobble. The minimum size material for secondary substrate is fine sand and the largest is bedrock. The median and mode material size for secondary substrate is cobble. The average slope is 8.2 degrees. The minimum slope is 1 degree and the maximum slope is 33 degrees. The median slope is 7.5 degrees and the mode is 6 degrees.

Site 7

The average material size for site 7 is boulder. The minimum size material is pebble and the largest is bedrock. The median material size is boulder and mode material size is bedrock. The average secondary substrate size is cobble. The minimum size material for secondary substrate is granule and the largest is boulder. The median and mode material size for secondary substrate is cobble. The average slope is 18 degrees. The minimum slope is 3 degrees and the maximum slope is 75 degrees. The median slope is 12 degrees and the mode is 6 degrees.

Site 8

The average material size for site 8 is cobble. The minimum size material is silt and the largest is bedrock. The median and mode material size is pebble. The average secondary substrate size is cobble. The minimum size material for secondary substrate is fine sand and the largest is bedrock. The median and mode material size for secondary substrate is cobble. The average slope is 11.5 degrees. The minimum slope is 1.5 degrees and the maximum slope is 70 degrees. The median slope is 9 degrees and the mode is 8 degrees.

Site 9

The average material size for site 9 is granule. The minimum size material is silt and the largest is bedrock. The median and mode material size is pebble. The average secondary substrate size is pebble. The minimum size material for secondary substrate is fine sand and the largest is bedrock. The median and mode material size for secondary substrate is pebble. The average slope is 7.5 degrees. The minimum slope is 2.5 degrees and the maximum slope is 22 degrees. The median slope is 7.8 degrees and the mode is 9 degrees.

Site 10

The average material size for site 10 is boulder. The minimum size material is pebble and the largest is bedrock. The median and mode material size is boulder. The average secondary substrate size is cobble. The minimum size material for secondary substrate is pebble and the largest is bedrock. The median and mode material size for secondary substrate is cobble. The average slope is 13.1 degrees. The minimum slope is 5 degrees and the maximum slope is 44.5 degrees. The median slope is 8.3 degrees and the mode is 6.5 degrees.

Site 11

The average material size for site 11 is cobble. The minimum size material is fine sand and the largest is bedrock. The median and mode material size is pebble. The average secondary substrate size is cobble.

The minimum size material for secondary substrate is fine sand and the largest is bedrock. The median and mode material size for secondary substrate is cobble. The average slope is 16.5 degrees. The minimum slope is 3 degrees and the maximum slope is 90 degrees. The median slope is 9 degrees and the mode is 8 degrees.

Site 12

The average material size for site 12 is cobble. The minimum size material is silt and the largest is bedrock. The median material size is cobble and mode material size is pebble. The average secondary substrate size is cobble. The minimum size material for secondary substrate is silt and the largest is bedrock. The median and mode material size for secondary substrate is cobble. The average slope is 13.9 degrees. The minimum slope is 2 degrees and the maximum slope is 65 degrees. The median slope is 8 degrees and the mode is 5 degrees.

Site 13

The average material size for site 13 is cobble. The minimum size material is fine sand and the largest is bedrock. The median material size is cobble and mode material size is bedrock. The average secondary substrate size is cobble. The minimum size material for secondary substrate is coarse sand and the largest is bedrock. The median material size for secondary substrate is cobble and mode material size is bedrock. The average slope is 16.2 degrees. The minimum slope is 2 degrees and the maximum slope is 45 degrees. The median slope is 8.8 degrees and the mode is 7 degrees.

Site 14

The average material size for site 14 is granule. The minimum size material is silt and the largest is cobble. The median and mode material size is pebble. The average secondary substrate size is pebble. The minimum size material for secondary substrate is silt and the largest is boulder. The median and mode material size for secondary substrate is cobble. The average slope is 6.7 degrees. The minimum slope is 1.5 degrees and the maximum slope is 15.5 degrees. The median slope is 6.5 degrees and the mode is 7.5 degrees.

Site 15

The average material size for site 15 is cobble. The minimum size material is silt and the largest is bedrock. The median and mode material size is cobble. The average secondary substrate size is boulder. The minimum size material for secondary substrate is silt and the largest is bedrock. The median material size for secondary substrate is boulder and mode material size is bedrock. The average slope is 15.4

degrees. The minimum slope is 4 degrees and the maximum slope is 55 degrees. The median slope is 10 degrees and the mode is 8 degrees.

Site 16

The average material size for site 16 is boulder. The minimum size material is granule and the largest is bedrock. The median material size is boulder and mode material size is bedrock. The average secondary substrate size is boulder. The minimum size material for secondary substrate is granule and the largest is bedrock. The median material size for secondary substrate is boulder and mode material size is bedrock. The average slope is 31.9 degrees. The minimum slope is 4 degrees and the maximum slope is 89 degrees. The median slope is 26 degrees and the mode is 35 degrees.

Site 17

The average material size for site 17 is boulder. The minimum size material is pebble and the largest is bedrock. The median material size is bedrock and mode material size is bedrock. The average secondary substrate size is boulder. The minimum size material for secondary substrate is pebble and the largest is bedrock. The median material size for secondary substrate is boulder and mode material size is bedrock. The average slope is 27 degrees. The minimum slope is 4 degrees and the maximum slope is 50 degrees. The median slope is 26 degrees and the mode is 50 degrees.

Site 18

The average material size for site 18 is pebble. The minimum size material is silt and the largest is bedrock. The median and mode material size is pebble. The average secondary substrate size is pebble. The minimum size material for secondary substrate is silt and the largest is bedrock. The median and mode material size for secondary substrate is cobble. The average slope is 11.7 degrees. The minimum slope is 1.5 degrees and the maximum slope is 70 degrees. The median slope is 9 degrees and the mode is 6 degrees.

Site 19

This site was not mapped as part of the CoastWalkers program.

Site 20

The average material size for site 20 is granule. The minimum size material is silt and the largest is bedrock. The median and mode material size is pebble. The average secondary substrate size is granule. The minimum size material for secondary substrate is silt and the largest is bedrock. The median material size for secondary substrate is pebble and mode material size is cobble. The average slope is 8.1 degrees.

The minimum slope is 0.5 degrees and the maximum slope is 55 degrees. The median slope is 7.5 degrees and the mode is 10 degrees.

Site 21
This site was not mapped as part of the CoastWalkers program.

Site 22
This site was not mapped as part of the CoastWalkers program.

5.4 SUMMARY OF POTENTIAL EFFECTS ON THE 22 SITES

This section summarizes the information provided above for each site. It is intended to provide the reader with an understanding of the vessel wake effects on the specific beaches. This evaluation is for the current quota and vessel restrictions so the evaluation of a site could change if the number of vessels permitted to enter Glacier Bay proper increases or decreases. See Table 8 for a summary of the overall potential affect to Glacier Bay National Park and Preserve due to vessels.

Site 1
Site 1 is generally a sandy beach with some larger material. This means that the beach has a high to moderate potential for erosion. However, the potential for vessel wakes to adversely affect the site at the current quota is negligible. Therefore, this site has a negligible potential for adverse affects at the current quota.

Site 2
Site 2 is generally a pebbled beach with cobbles. This means that the beach has a moderate potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is minor. Therefore, this site has a minor potential for adverse affects at the current quota.

Site 3
Site 3 is generally a cobbled to sandy beach that also has a significant amount of boulders and bedrock. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is negligible. Therefore, this site has a negligible potential for adverse affects at the current quota.

Site 4

Site 4 is generally a cobbled beach with larger material including boulders. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is minor. Therefore, this site has a minor potential for adverse affects at the current quota.

Site 5

Site 5 is generally a pebbled beach. This means that the beach has a moderate potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is minor. Therefore, this site has a minor potential for adverse affects at the current quota.

Site 6

Site 6 is generally a pebbled beach with larger material including cobbles. This means that the beach has a moderate to minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is negligible. Therefore, this site has a negligible potential for adverse affects at the current quota.

Site 7

Site 7 is generally a boulder beach. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is negligible. Therefore, this site has a negligible potential for adverse affects at the current quota.

Site 8

Site 8 is generally a cobbled beach with both larger material including bedrock and some smaller material including silt. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is negligible. Therefore, this site has a negligible potential for adverse affects at the current quota.

Site 9

Site 9 is generally a granular beach with pebbles. This means that the beach has a high to moderate potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is negligible to minor. Therefore, this site has a minor potential for adverse affects at the current quota.

Site 10
Site 10 is generally a boulder beach with cobbles. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is negligible. Therefore, this site has a negligible potential for adverse affects at the current quota.

Site 11
Site 11 is generally a cobbled beach. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is minor to negligible. Therefore, this site has a minor potential for adverse affects at the current quota.

Site 12
Site 12 is generally a cobbled beach. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is minor to negligible. Therefore, this site has a minor potential for adverse affects at the current quota.

Site 13
Site 13 is generally a cobbled beach with exposed bedrock. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is negligible. Therefore, this site has a negligible potential for adverse affects at the current quota.

Site 14
Site 14 is generally a granular beach with pebbles and cobbles. This means that the beach has a high to moderate potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is negligible to minor. Therefore, this site has a minor potential for adverse affects at the current quota.

Site 15
Site 15 is generally a cobble beach with larger material including boulders and bedrock. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is minor. Therefore, this site has a minor potential for adverse affects at the current quota.

Site 16
Site 16 is generally a boulder beach with bedrock. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is moderate to

negligible. Therefore, this site has a minor potential for adverse affects at the current quota due to the larger material size of the substrate.

Site 17

Site 17 is generally a boulder beach with bedrock. This means that the beach has a minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is minor. Therefore, this site has a minor potential for adverse affects at the current quota.

Site 18

Site 18 is generally a pebbled beach with some cobbles. This means that the beach has a moderate to minor potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is minor to negligible. Therefore, this site has a minor potential for adverse affects at the current quota.

Site 19

Physical attribute information is not available for Site 19. This site is in Muir Inlet and outside the area mapped for the NPS during the CoastWalkers project. A glacier covered the site as recently as 40 years ago. The potential for vessel wakes to adversely affect the site at the current quota is negligible. More information on the shoreline material is necessary to determine the overall potential affect.

Site 20

Site 20 is generally a granular beach with some pebbles. This means that the beach has a high potential for erosion. The potential for vessel wakes to adversely affect the site at the current quota is negligible. Therefore, this site has a negligible potential for adverse affects at the current quota.

Site 21

Physical attribute information is not available for Site 21. This site is in the upper reaches of Muir Inlet and outside the area mapped for the NPS. A glacier covered the site as recently as 30 years ago. The potential for vessel wakes to adversely affect the site at the current quota is negligible. More information on the shoreline material is necessary to determine the overall potential affect.

Site 22

Physical attribute information is not available for Site 22. This site is on South Marble Island and outside the area mapped for the NPS. Seabird activity on the island was noted during the cruise tour and maps indicate that this site is a seabird nesting area. The potential for vessel wakes to adversely affect the site at the current quota is minor. More information on the shoreline material is necessary to determine the overall potential affect.

TABLE 8 POTENTIAL FOR ADVERSE AFFECTS AT 22 SITES IN GLACIER BAY NATIONAL PARK AND PRESERVE WITH THE 1996 VESSEL "USE DAYS".

Site	Erosion Potential at the Site	Vessel Wake Potential Effect[7]	Overall Potential Effect[8]
1	High to moderate	Negligible	Negligible
2	Moderate	Minor	Minor
3	Minor	Negligible	Negligible
4	Minor	Minor	Minor
5	Moderate	Minor	Minor
6	Moderate to minor	Negligible	Negligible
7	Minor	Negligible	Negligible
8	Minor	Negligible	Negligible
9	High to moderate	Negligible to minor	Minor
10	Minor	Negligible	Negligible
11	Minor	Minor to negligible	Minor
12	Minor	Minor to negligible	Minor
13	Minor	Negligible	Negligible
14	High to moderate	Negligible to minor	Minor
15	Minor	Minor	Minor
16	Minor	Moderate to negligible	Minor
17	Minor	Minor	Minor
18	Moderate to minor	Minor to negligible	Minor
19	Not mapped	Negligible	*Need additional information*
20	High	Negligible	Negligible
21	Not mapped	Negligible	*Need additional information*
22	Not mapped	Minor	*Need additional information*

5.5 WAKE EFFECTS ON WATERWAY USERS

The tide range in Glacier Bay proper is approximately 24 feet. With mixed tides the bay daily experiences two different high tide levels and two different low tide levels (see Figure 12). A high tide is followed by a higher low, which is followed by a higher high, which is followed by a lower low. Twice a month, due to alignment of the sun and moon, spring tides occur. For approximately two days, both higher highs and lower lows are exaggerated. Although spring tides occur twice a month, the most exaggerated spring tides occur in the spring season when large vessel traffic is absent in Glacier Bay proper.

[7] 1996 vessel quotas.
[8] 1996 vessel quotas.

There are many waterway users that may be in the vicinity of the shoreline. These users can include nesting birds, kayakers, and campers. For this section, shore nesting birds will be used as an example of potentially affected users. Most shore nesting birds establish their nests to minimize swamping due to waves and with consideration of the tides and typical storms during the nesting season. Some birds may be forced into the marginal areas and be at higher risk for swamping during natural conditions and when vessels are not present. Swamping of shore nesting birds is most likely to occur when boat wakes occur simultaneously with higher high spring tides. The probability that a vessel wake will wash over a nest is equal to the probability of a spring tide occurring times the probability that the nests are placed low on the beach and "too close to the high water level."

The probability of a higher high spring tide is equal to the number of hours of higher high spring tides a season divided by the number of hours in the season. This probability is 0.56%, calculated as follows:

$$\frac{1\mathrm{hr}}{(\mathrm{higher}-\mathrm{high})\mathrm{tide}}\cdot\frac{1\,(\mathrm{higher}-\mathrm{high})\mathrm{tide}}{\mathrm{day}}\cdot\frac{4\mathrm{day}}{\mathrm{month}}\cdot\frac{3\mathrm{month}}{\mathrm{season}}\div\frac{24\mathrm{hr}}{\mathrm{day}}\cdot\frac{30\mathrm{day}}{\mathrm{month}}\cdot\frac{3\mathrm{month}}{\mathrm{season}}$$

The analysis of whether a nest will be swamped due to vessel wakes can be carried over to any shoreline user. For example, if a kayaker pulls their kayak above the higher high tide line, the probability that the kayak will be swamped and possible pulled out into the bay is the same as the example above, 0.56%. However, if the kayak is not pulled up to this point on the beach, then the probability of the kayak being swamped will increase depending on the location of the kayak and the tide range during that time.

5.6 WAVE PARAMETERS CONSIDERED BUT NOT SELECTED FOR THE DETAILED ANALYSIS

Another parameter besides energy was calculated and compared to wave energy at selected sites to provide an alternative method of evaluating vessel wake impacts to the Glacier Bay proper ecosystem. This wave parameter is water particle velocity and it relates to long shore transport.

Maximum water particle velocities were considered. Water particle velocities stir up the sediments by exerting drag on the sediment particles. The motion of the water under surface waves (for which gravity is the restoring force) is circular near the surface. As the depth increases, the motion becomes elliptical. Very near the bottom, the water can be imagined as moving back and forth.

Example calculations of water particle velocities showed that for the wave heights and periods typical of the wave climate in Glacier Bay proper, the velocities would be more difficult to compare in the various sites of interest because additional input parameters are required. These include the wave speed, C, and the period of the vessel waves. The calculations performed show that the typical particle velocities were smaller than the design velocity of 10 feet per second (fps), which is used in aquariums to prevent marine fouling. Velocities of less than 10 fps are inferred to be required to allow marine growth. Velocities in the range of 10 fps do routinely occur in the shallow surf zone during wind wave events. Even in the shallowest water, as predicted by Airy theory, the maximum horizontal water particle velocity caused by the design boat wake is approximately 3 fps.

Water particle velocity was not as suitable a parameter for analysis of vessel wake effects in Glacier Bay proper. The additional input information required is not readily available and would require making additional assumptions.

6 CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

The purpose of this technical memorandum is to provide a method to evaluate existing and proposed vessel quotas and operating requirements in Glacier Bay National Park and Preserve. The method detailed in this technical memorandum will be used to classify all sites selected for full evaluation in the EIS. Some conclusions can be drawn based on our work so far and on the information contained within this technical memorandum. These include:

- For most of Glacier Bay proper, vessel wakes pose little threat to the coastline.
- There are specific locations where operating requirements may be necessary to prevent adverse effect to the shoreline. This may include creating a no-wake zone near the shoreline. See the Environmental Impact Statement for specific sites and evaluations.
- The potential effect of vessel generated internal waves to all aspects of the environment is not known. Research indicates that internal waves have the potential to mix stratified layers of water. This could affect stratification of pelagic organisms like algae. Further scientific study is required to determine if they exist and their affects on the environment. It is likely that naturally occurring internal waves occur in Glacier Bay proper and would not be affected by vessels due to the shallow extent of influence by the vessel.
- Vessel wake disturbance occurs close to the vessel producing the wake. Wakes are essentially dissipated within 2,000 feet of the vessel.

- Requiring vessels to stay farther from shore during the hour of higher-high spring tides will guard against the possibility of wakes washing over nesting sites.
- Wave climates (both natural and vessel induced) affect near shore and tidal users. The height of the tide is an important factor in whether the vessel-induced wake would affect the user.
- Erosion due to beaching vessels is more likely to cause erosion at a specific site than vessel wakes.

Data is needed in the following areas:

- Wind data in several key locations throughout the park. Wind data used in this memorandum is not specific for Glacier Bay and thus only extrapolated.
- Accurate vessel track data is needed. This is the weakest element in the analysis.
- Waves should be measured in the bay to provide validation of the energy indices, N values.
- Effects of ship induced internal waves on the water column.

7 DEFINITIONS

Average – This is the typical quantity, also known as the mean.

Beach – In coastal engineering a beach or shore encompasses the extents shown in Figure 10. Rocky beaches (for instance) will not have all the features, but will have the same zones that are defined by the water levels shown in the figure.

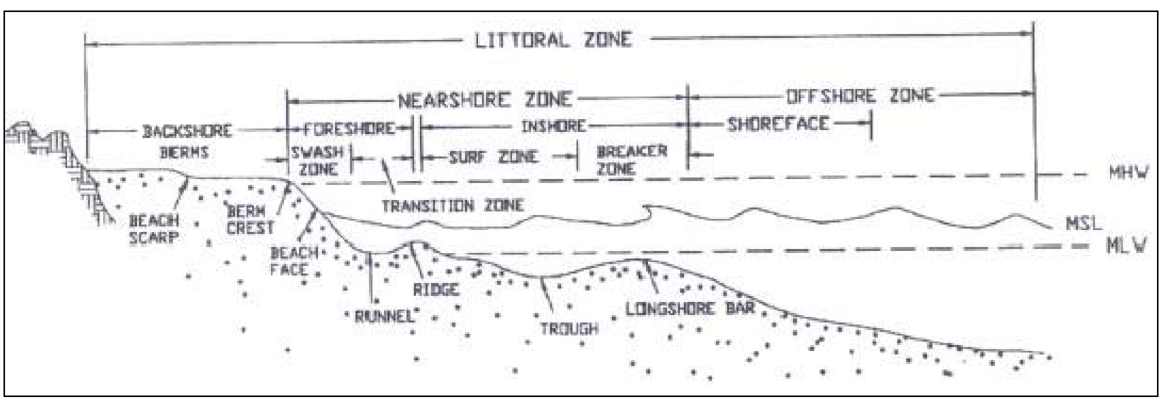


FIGURE 10 BEACH TERMINOLOGY AND EXTENTS.

Beam – vessel maximum width normal to flow, see Figure 11 (B on the drawing).

Blockage Ratio – cross sectional area of waterway divided by the maximum submerged cross section of the vessel. A maximum blockage ratio of 60 in Glacier Bay proper would occur if a cruise ship traversed the 0.25 mile wide channel north of Russell Island.

Constricted waterway – a navigated waterway with blockage ratio less than 20.

Deep water – related to a wave's position in the water, where d satisfies $0.5 < \frac{d}{L} <$ infinity, see Figure 13.

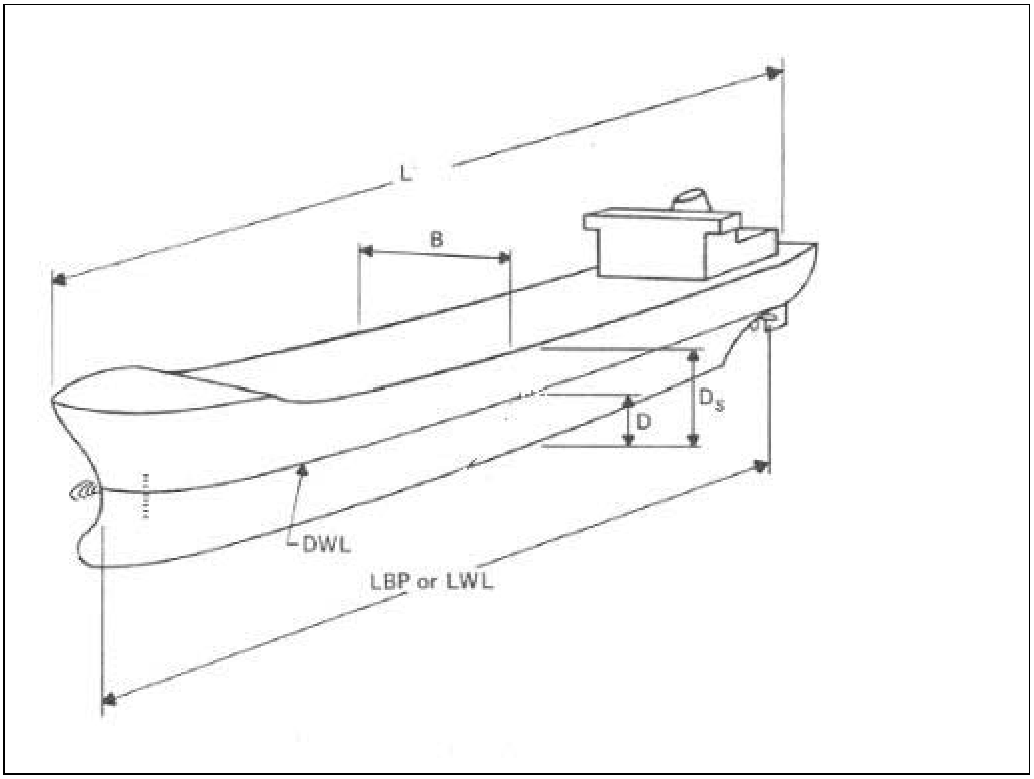


FIGURE 11 VESSEL DIMENSIONS

Diverging Wake – the wave which spreads outward from the boats bow and is always present

Fetch – the unobstructed area in which waves are generated by a wind having a rather constant direction and speed

Mean Lower Low Water (MLLW) is the 0 water level in Figure 12, and is the datum referenced in coastal engineering. Glacier Bay has what is called mixed tides, with one small and one large tide a day. Referenced water levels are averaged over a period of years to establish the datum.

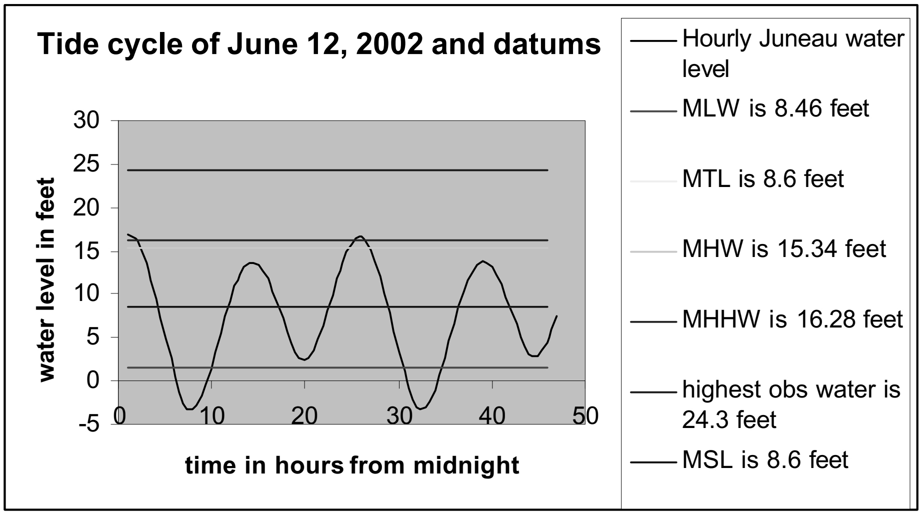


FIGURE 12 TIDES IN JUNEAU.

Median – The middle number of a given sequence of numbers, as used in statistical analysis.

Mode – The number that occurs most frequently in a given sequence of numbers, as used in statistical analysis.

Negative tide - when the water is below the usual low water mark (0 MLLW), as on the day of June 12 in Gustavus, see Figure 12. This occurs twice monthly.

Orographic effects - effects attributed to mountains.

Propagation Speed – the same as wave speed, or celerity.

Ship (Vessel) Track Line – the path over the water.

Spring Tide – Tides which occur twice monthly and have both higher highs and lower lows. The most extreme spring tides do occur during the spring before boats begin to enter Glacier Bay, but the term is used throughout the seasons.

Transverse Wake – the wave which is directed opposite the boats motion, is caused by the boats stern and is sometimes present.

Wave height or amplitude – Shown as H in Figure 13.

Wave period – the length of time which a stationary observer on the surface of the water observes between two successive crests.

Wave length – L in Figure 13

Wave speed – the speed at which the wave propagates or advances, usually referred to as C, or wave celerity. See Figure 13.

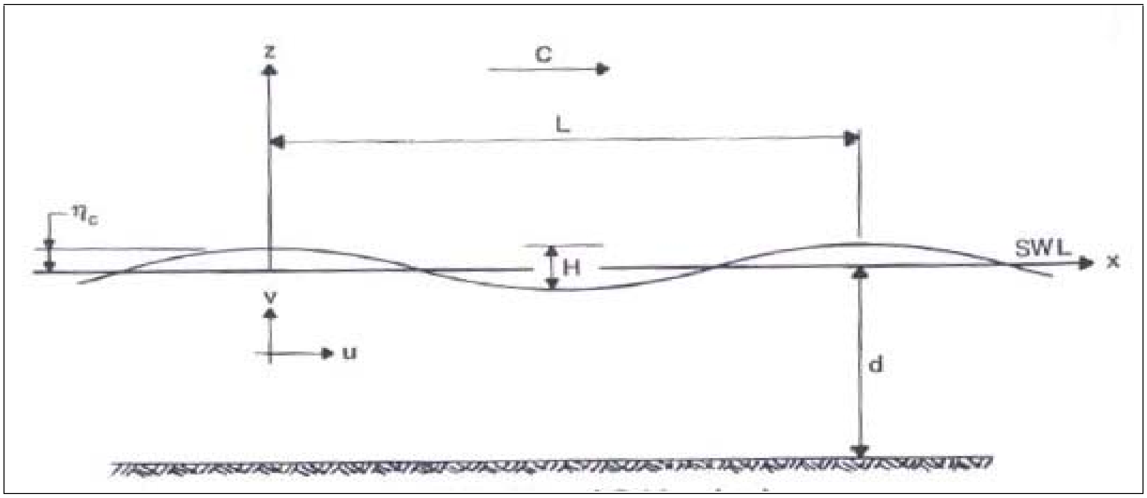


FIGURE 13 WAVE PARAMETER DEFINITIONS

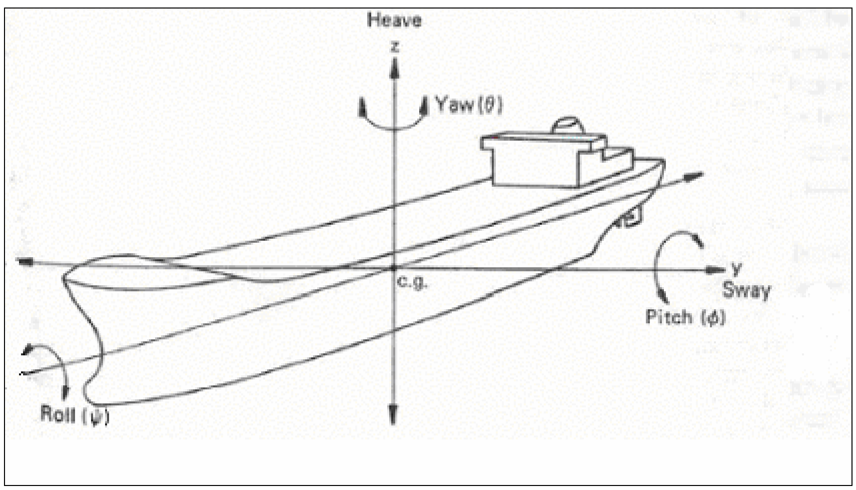


FIGURE 14 VESSEL MOTION DEFINITIONS

8 REFERENCES

Alaska Sea Atlas Website (under construction during July, 2002), http://holmes-iv.engr.uaa.alaska.edu/

Arctic Environmental Information and Data Center. 1984, "Extreme wind predictions for first order weather stations in Alaska", Alaska Climate Center Technical Note No 1, University of Alaska Fairbanks, Fairbanks, AK

Avitol, E., and Miloh, T., 1999. "On an inverse problem of ship-induced internal waves," Ocean Engineering, v. 26, Pergammon, pp. 99-110.

Blaauw H., de Groot, M., van der Knaap, F., and Pilarczyk, K., 1984. "Design of Bank Protection for Inland Navigation Fairways," Proc., Flexible Armour Revetments Incorporating Geotextiles Conference, Inst. Civil Engineers, London

Cushman-Roisin, B., 1994. Introduction to Geophysical Fluid Dynamics, Prentice Hall, Englewood Cliffs, NJ

Ekman, V., 1904. "On Dead Water," Scientific Results, Norwegian Polar Expedition 1893-96, v. 5, no. 15.

Froude, W., 1877. "On experiments upon the effect produced on the wave-making resistance of ship by length of parallel middle body," Transactions, Institute of Naval Architects, v. 22, London, pp. 220-224.

Gates, E.T. and Herbich, J.B. 1977. "*Mathematical Model to Predict the Behavior of Deep-draft Vessels in Restricted Waterways*". Report TAMU-SG-77-206, Texas A & M University, College Station, TX.

Hooge, P. and Hooge, E., 2001. "Fjord Oceanographic Processes in Glacier Bay, Alaska," USGS-Alaska Biological Science Center, Glacier Bay Field Station, Gustavus, AK, for National Park Service, Glacier Bay National Park and Preserve

Gaythwaite, J.W., 1990, Design of marine facilities for berthing, mooring and repair of vessels, Von Nostrand Reinhold, New York, NY

Gross, M.G. 1972, Oceanography a view of the earth, Prentice-Hall, Inc, Englewood Cliffs, NJ

Hüsig, A., Linke, T., and Zimmerman, C., (May) 2000. "Effects from Supercritical Ship Operation on Inland Canals," J. Waterway, Port, Coastal, and Ocean Engineering, American Society of Civil Engineers, NY, pp. 130-135.

Maynord, S.T. 2001. "B*oat Waves on Johnson Lake and Kenai River, Alaska*". United States Army Corp of Engineers Engineering Research and Development Center Technical Report, Vicksburg, MS.

National Park Service, Glacier Bay National Park, 20020527, Glacier Bay Coastal Inventory segments, polygons, shapefiles, Gustavus, Alaska. "CoastWalkers". See also \\barco\SCIENCE\eco_data\data\glba\COASTAL\Coast_97\Gis\ToAKSO\2002-05-27\Shapefiles

National Park Service, Glacier Bay National Park, 2002. NOAA_cst.shp, csroutes_2002-09-17.shp, and charters-2002-07-15.shp. Gustavus, AK.

PIANC, 1987. "Guidelines for the Design and Construction of Flexible Revetments Incorporating Geotextiles for Inland Waterways," International Navigation Association (PIANC), Brussels

Short, A.D. 1991. "Macro-meso Tidal Beach Morphodynamics – An Overview", Journal of Coastal Research, Vol 7, No. 2. pp 417-436.

Smith, O.P. 1987. "Hydraulic Force Parameters Associated with Internal Waves", unpublished term paper for CE 681.

Sorensen, R. M. 1973. *"Ship Generated Waves*". Advances in Hydroscience. Vol 9, Academic Press, NY, NY Vol 9, pp49-83.

Sorensen, R. M. 1989. "*Port and Channel Bank Protection from Ship Waves*". Proceedings, Ports 89 Conference, American Society of Civil Engineers, Oakland, CA.

Thompson, W. (Lord Kelvin), 1887. "On Ship Waves," Transactions, Institute of Mechanical Engineering, London, pp. 409-433.

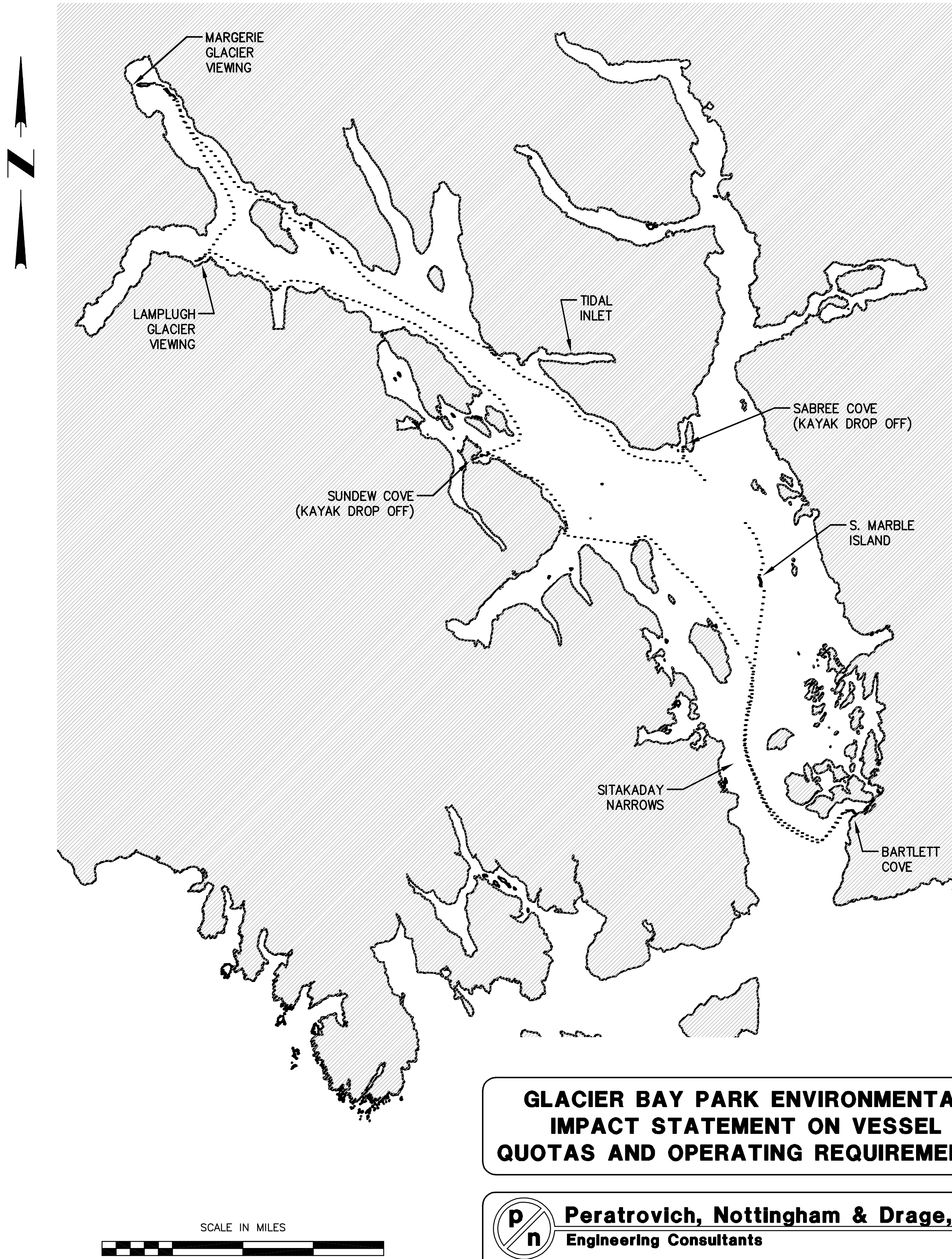
Umeyama, Mothiko, 2002. "Experimental and Theoretical Analyses of Internal Waves of Finite Amplitude," J. Waterway, Port, Coastal, and Ocean Engineering, 128/3, American Society of Civil Engineering, NY

United States Army Corp of Engineers. 2002. *Coastal Engineering Manual (Draft as of May 2002)*

Veri-Tech, 2002. "Vessel-Generated Waves," CEDAS, ACES software system, v. 2.01 (Harbor Design Module), Veri-Tech, Inc., Jackson, MS

Weggel, J.R. and Sorensen, R.M. 1986. "*Ship Wave Prediction for Port and Channel Design".* Proceedings, Ports 86 Conference, ASCE, Oakland, CA., pp 794-814

Wuebben, J., Hunter, L., Lawson, D., and Bigl, S., 2000. "Impact Study of Vessel Effects on the Marine and Nearshore Zone, Glacier Bay, Alaska," ERDC/CRREL LR-00-01, US Army Cold Regions Research and Engineering Laboratory, Hanover, NH, for National Park Service, Glacier Bay National Park and Preserve and Preserve



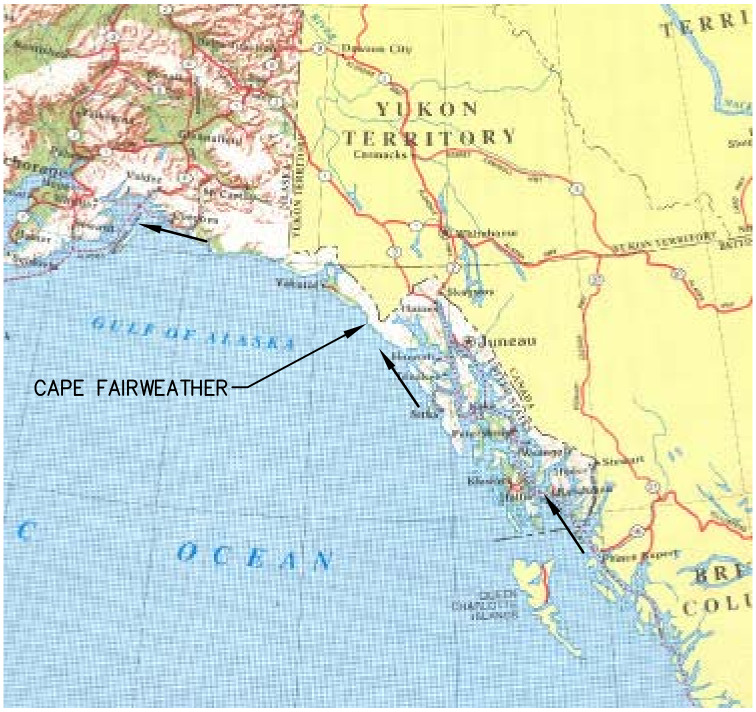
GLACIER BAY PARK ENVIRONMENTAL IMPACT STATEMENT ON VESSEL QUOTAS AND OPERATING REQUIREMENTS

Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants

1506 West 36th Avenue,
Anchorage, Alaska 99503 (907) 561-1011 FAX (907) 563-4220

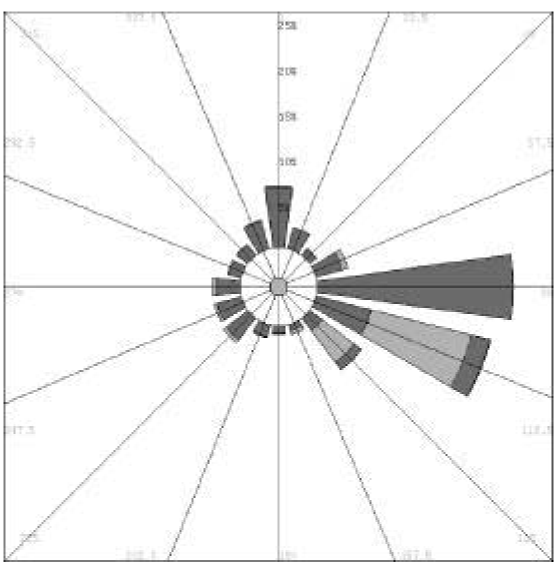
SPIRIT OF ADVENTURE CRUISE WAY POINTS - JUNE 12, 2002

PLATE 1



VICINITY MAP

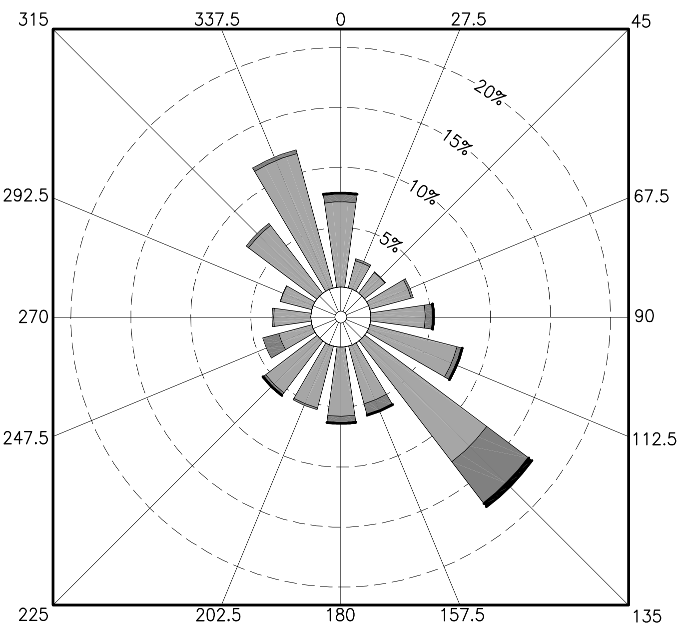
STATION: JUNEAU, AK
YEARS: 1987 – 1999
MONTHS: ALL
DAYS: ALL
HOURS: ALL
SOURCE: AK SEA ATLAS WEBSITE, TDF14, TD3280 – HOURLY



JUNEAU, ALASKA

STATION: GUSTAVUS, AK
YEARS: 1987 – 2001
MONTHS: ALL
DAYS: ALL
HOURS: ALL
SOURCE: NATIONAL CLIMATE DATA CENTER – HOURLY

NOTE:
RADIAL BANDS INDICATE 10 KNOT INCREMENTS OF WIND ACTING TOWARD THE CENTER OF THE WIND ROSE.



GUSTAVUS, ALASKA

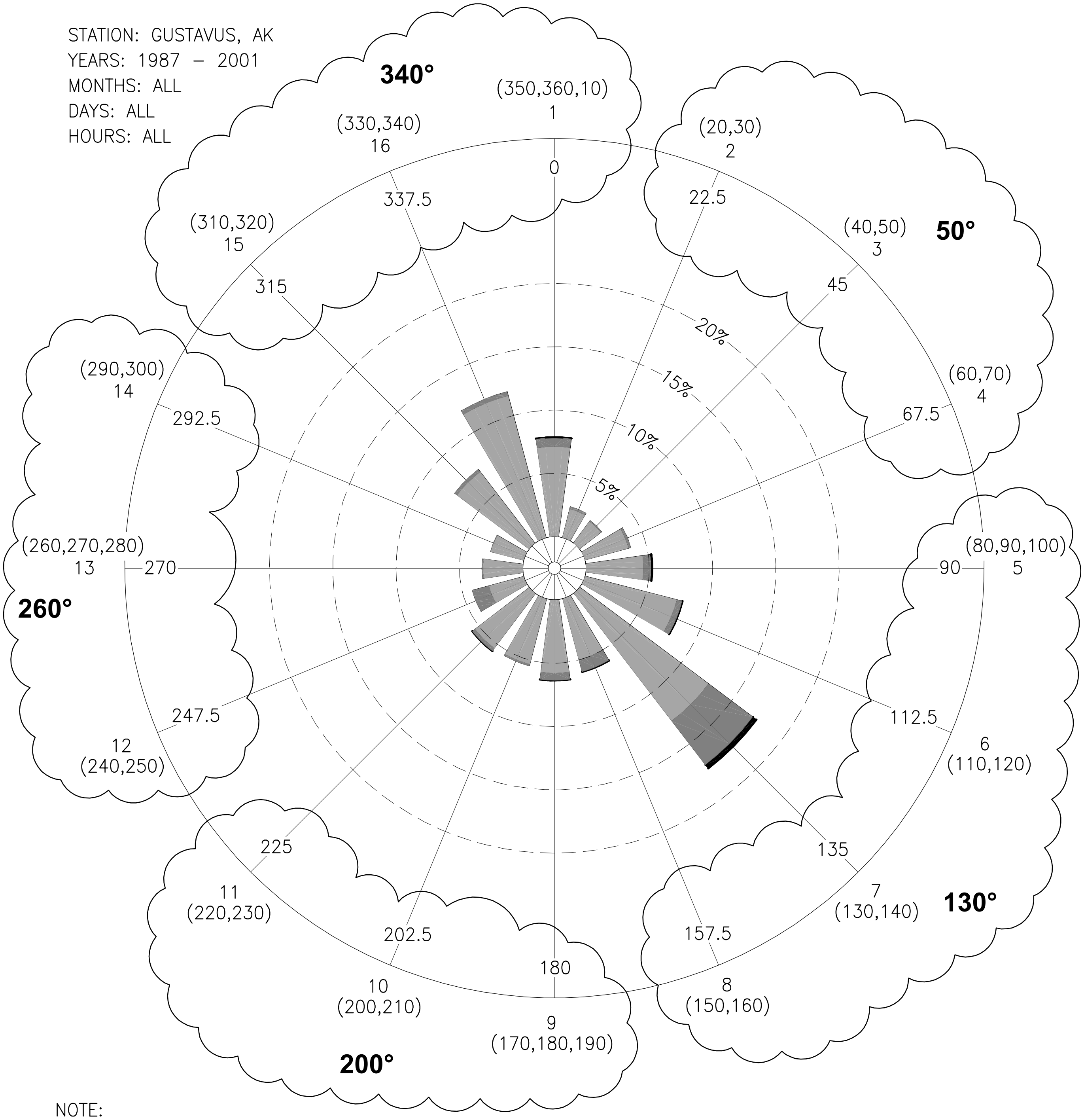
GLACIER BAY PARK ENVIRONMENTAL IMPACT STATEMENT ON VESSEL QUOTAS AND OPERATING REQUIREMENTS

Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants

1506 West 36th Avenue,
Anchorage, Alaska 99503 (907) 561-1011 FAX (907) 563-4220

WIND ROSE COMPARSION

PLATE 2



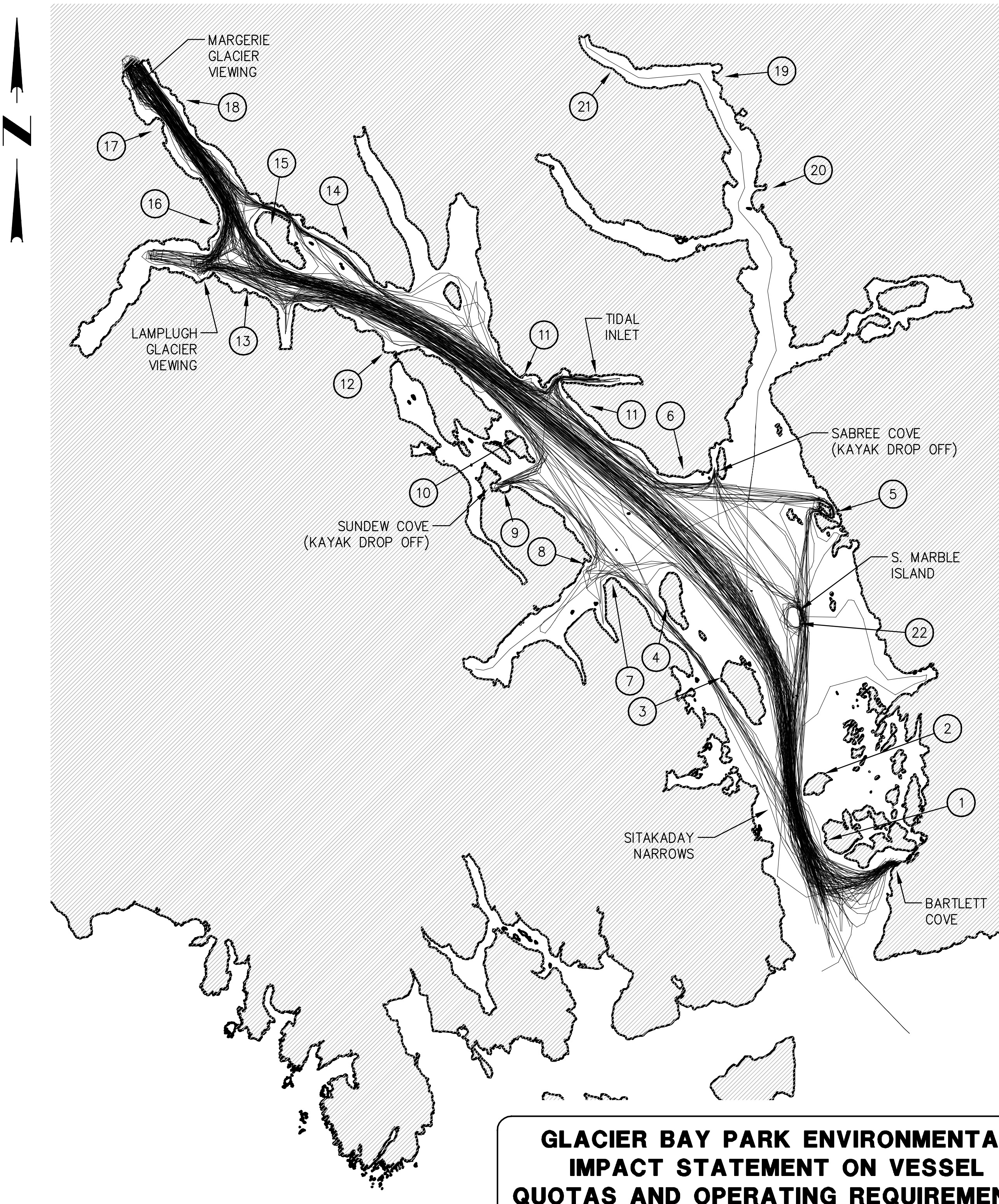
NOTE:
1. RADIAL BANDS INDICATE 10 KNOT INCREMENTS OF WIND ACTING TOWARD THE CENTER OF THE WIND ROSE.
2. NUMBERS 1 TO 16 REPRESENT SECTOR BINS.
3. NUMBERS IN PARENTHESIS REPRESENT THE WIND DIRECTIONS REPORTED BY NCDC WHICH WERE ASSIGNED TO EACH SECTOR BIN.
4. BOLD NUMBERS IN OUTER CLOUDS REPRESENT THE WIND ASSIGNED TO THE CLOUDED SECTORS FOR WAVE GROWTH ANALYSIS.

GLACIER BAY PARK ENVIRONMENTAL IMPACT STATEMENT ON VESSEL QUOTAS AND OPERATING REQUIREMENTS

Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants
1506 West 36th Avenue,
Anchorage, Alaska 99503 (907) 561-1011 FAX (907) 563-4220

BIN ARRANGEMENT FOR WIND ANALYSIS

PLATE 3



NOTES:
NUMBERS INDICATE SHORELINE IDENTIFIED FOR DETAILED STUDY.

GLACIER BAY PARK ENVIRONMENTAL IMPACT STATEMENT ON VESSEL QUOTAS AND OPERATING REQUIREMENTS

Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants

1506 West 36th Avenue,
Anchorage, Alaska 99503 (907) 561-1011 FAX (907) 563-4220

GLACIER BAY VESSEL TRAFFIC

PLATE
4

Gustavus probabilities summarized as described in technical memo

assigned angle	sector		calm	1-9kn	10-19kn	20-29kn	30-39kn	40-49kn	50-max
	1*	0	0.30	4.9707	0.5096	0.0056	0.0000	0.0000	0.0000
	2	22.5		1.6352	0.1333	0.0011	0.0000	0.0000	0.0000
	3	45		1.4919	0.0605	0.0011	0.0000	0.0000	0.0000
	4	67.5		2.4966	0.1434	0.0011	0.0000	0.0000	0.0000
50				**5.6237**	**0.3371**	**0.0034**	**0.0000**	**0.0000**	**0.0000**
	5	90		3.1708	0.4839	0.0056	0.0000	0.0000	0.0000
	6	112.5		5.2451	0.3125	0.0123	0.0000	0.0000	0.0000
	7	135		8.8976	3.0633	0.2464	0.0011	0.0011	0.0000
	8	157.5		3.4878	0.6843	0.0202	0.0000	0.0000	0.0000
135				**20.8013**	**4.5440**	**0.2845**	**0.0011**	**0.0011**	**0.0000**
	9	180		4.0467	0.4077	0.0090	0.0000	0.0000	0.0000
	10	202.5		3.7208	0.0997	0.0022	0.0000	0.0000	0.0011
	11	225		3.7824	0.1904	0.0056	0.0000	0.0022	0.0000
200				**11.5498**	**0.6978**	**0.0168**	**0.0000**	**0.0022**	**0.0011**
	12	247.5		2.0037	0.9554	0.0022	0.0000	0.0022	0.0022
	13	270		2.1684	0.0918	0.0011	0.0000	0.0000	0.0000
	14	292.5		1.8805	0.0202	0.0000	0.0011	0.0011	0.0011
260				**6.0527**	**1.0674**	**0.0034**	**0.0011**	**0.0034**	**0.0034**
	15	315		4.9741	0.1736	0.0000	0.0000	0.0000	0.0000
	16	337.5		8.1247	0.2363	0.0034	0.0000	0.0000	0.0000
340				**18.0695**	**0.9195**	**0.0090**	**0.0000**	**0.0000**	**0.0000**
		% totals	30.34	62.0969	7.5658	0.3170	0.0022	0.0067	0.0045

Juneau summaried as Gustavus

assigned angle	sector		calm	1-9kn	10-19kn	20-29kn	30-39kn	40-49kn	50-max
	1*	0	0.22	6.6959	0.0827	0.0018	0.0000	0.0000	0.0000
	2	22.5		2.4436	0.0361	0.0018	0.0000	0.0000	0.0000
	3	45		0.9329	0.0774	0.0026	0.0000	0.0000	0.0000
	4	67.5		2.9448	0.7131	0.0149	0.0000	0.0000	0.0000
50				**6.3213**	**0.8265**	**0.0193**	**0.0000**	**0.0000**	**0.0000**
	5	90		10.4469	6.7407	0.2814	0.0009	0.0009	0.0000
	6	112.5		6.2193	11.4397	2.0681	0.0985	0.0009	0.0000
	7	135		1.7498	4.4018	1.0446	0.0440	0.0000	0.0000
	8	157.5		0.7131	0.4282	0.0457	0.0000	0.0000	0.0000
135				**19.1291**	**23.0104**	**3.4398**	**0.1433**	**0.0018**	**0.0000**
	9	180		0.8942	0.1196	0.0070	0.0000	0.0000	0.0000
	10	202.5		1.4095	0.1337	0.0035	0.0000	0.0000	0.0000
	11	225		3.0855	0.3816	0.0009	0.0000	0.0000	0.0000
200				**5.3892**	**0.6349**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
	12	247.5		2.7795	0.3878	0.0000	0.0000	0.0000	0.0000
	13	270		2.7258	0.4185	0.0000	0.0000	0.0000	0.0000
	14	292.5		1.4420	0.1196	0.0000	0.0000	0.0000	0.0000
260				**6.9473**	**0.9259**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
	15	315		1.5414	0.0404	0.0000	0.0000	0.0000	0.0000
	16	337.5		3.2745	0.0431	0.0000	0.0000	0.0000	0.0000
340				**11.5118**	**0.1662**	**0.0018**	**0.0000**	**0.0000**	**0.0000**
		% totals	21.52	49.2987	25.5639	3.4609	0.1433	0.0018	0.0000

* sector 1 added to direction assigned 340 degrees

records total Gustavus 1987-2001

calm	1-9kn	10-19kn	20-29kn	30-39kn	40-49kn	50-max	
27091	4438	455	5	0	0	0	4898
	1460	119	1	0	0	0	1580
	1332	54	1	0	0	0	1387
	2229	128	1	0	0	0	2358
50	**5021**	**301**	**3**	**0**	**0**	**0**	**5325**
	2831	432	5	0	0	0	3268
	4683	279	11	0	0	0	4973
	7944	2735	220	1	1	0	10901
	3114	611	18	0	0	0	3743
135	**18572**	**4057**	**254**	**1**	**1**	**0**	**22885**
	3613	364	8	0	0	0	3985
	3322	89	2	0	0	1	3414
	3377	170	5	0	2	0	3554
200	**10312**	**623**	**15**	**0**	**2**	**1**	**10953**
	1789	853	2	0	2	2	2648
	1936	82	1	0	0	0	2019
	1679	18	0	1	1	1	1700
260	**5404**	**953**	**3**	**1**	**3**	**3**	**6367**
	4441	155	0	0	0	0	4596
	7254	211	3	0	0	0	7468
340	**16133**	**821**	**8**	**0**	**0**	**0**	**16962**
	55442	6755	283	2	6	4	62492
						grand tot	89583

records total Juneau 1987-1999 (first order station)

calm	1-9kn	10-19kn	20-29kn	30-39kn	40-49kn	50-max	
24474	7615	94	2	0	0	0	7711
	2779	41	2	0	0	0	2822
	1061	88	3	0	0	0	1152
	3349	811	17	0	0	0	4177
50	**7189**	**940**	**22**	**0**	**0**	**0**	**8151**
	11881	7666	320	1	1	0	19869
	7073	13010	2352	112	1	0	22548
	1990	5006	1188	50	0	0	8234
	811	487	52	0	0	0	1350
135	**21755**	**26169**	**3912**	**163**	**2**	**0**	**52001**
	1017	136	8	0	0	0	1161
	1603	152	4	0	0	0	1759
	3509	434	1	0	0	0	3944
200	**6129**	**722**	**13**	**0**	**0**	**0**	**6864**
	3163	441	0	0	0	0	3604
	3100	476	0	0	0	0	3576
	1640	136	0	0	0	0	1776
260	**7903**	**1053**	**0**	**0**	**0**	**0**	**8956**
	1753	46	0	0	0	0	1799
	3724	49	0	0	0	0	3773
340	**13092**	**189**	**2**	**0**	**0**	**0**	**13283**
	56068	29073	3949	163	2	0	89255
						grand tot	113729

Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants
1506 West 36th Avenue Anchorage, Alaska 99503 (907) 561-1011 Fax (907) 563-4220

Memorandum

To: File — Project No.: 02056.02

From: Jennifer Wilson — Date: October 3, 2002

Re: *Wave Generation Model Calculations*

Project: Glacier Bay National Park and Preserve Vessel Quotas and Operating Requirements Environmental Impact Statement, Appendix F Technical Memorandum

---

The attached document, *Wave Generation Model Calculations*, provides the wave generation models used to calculate wave energy. The models calculate wave heights in restricted and unrestricted channels, deep versus shallow water, and the type of wave considering the shape of the vessel hull. Document created July 2002.

Ref. Sorensen, R. M., 1973. "Ship-Generated Waves," Advances in Hydroscience," v. 9, pp. 49-83.
(deep water)

$$C = V \cdot \cos(\theta)$$

C = ship wave propagation speed
V = ship velocity relative to the water
θ = angle between ship track and wave direction of propagation (wave ray)

$$\lambda = \frac{2 \cdot \pi \cdot V^2 \cdot \cos^2(\theta)}{g} \qquad T = \frac{2 \cdot \pi \cdot V \cdot \cos(\theta)}{g}$$

λ = wavelength (horizontal distance between crests along wave propagation direction)
g = acceleration of gravity

$$x = \left(\frac{n \cdot \pi \cdot V^2}{2 \cdot g}\right) \cdot (\sin(\alpha) + \sin(3 \cdot \alpha)) \qquad y = \left(\frac{-n \cdot \pi \cdot V^2}{2 \cdot g}\right) \cdot (5 \cdot \cos(\alpha) - \cos(3 \cdot \alpha))$$

x and y = coordinates of wave crest
α = angle between ship track and a line to the point (x,y)

$$F = \frac{V}{\sqrt{g \cdot d}} = \frac{\sqrt{\frac{g \cdot \lambda}{2 \cdot \pi}}}{\sqrt{g \cdot d}} = 0.56$$

F = Froude number limit for deep water transverse waves (d/λ = 0.5)

d = still water depth

at F > 0.6 - 0.7, ship waves respond to bottom (no longer deep water)

(shallow water)

$$\cos^2(\alpha) = \frac{8\cdot\left[1 - \left(\frac{2\cdot k\cdot d}{\sinh(2\cdot k\cdot d)}\right)\right]}{\left(3 - \frac{2\cdot k\cdot d}{\sinh(2\cdot k\cdot d)}\right)^2}$$ α = cusp locus angle

$$k = \frac{2\cdot\pi}{\lambda}$$ wave number

at F = 1, $V = C = C_g = \sqrt{g\cdot d}$ and $\alpha = 90\cdot\mathrm{deg}$

at F > 1, only diverging waves exist and transverse waves are no longer generated

$$\alpha = \mathrm{asin}\left(\frac{\sqrt{g\cdot d}}{V}\right)$$

$$V\cdot\cos(\theta) = \left(\frac{g\cdot T}{2\cdot\pi}\right)\tanh\left(\frac{2\cdot\pi\cdot d}{V\cdot T\cdot\cos(\theta)}\right)$$ general relation, V, θ, d, and T

ref. Sorensen, R.M., 1989. "Port and Channel Bank Protection from Ship Waves," Proc., Ports '89, ASCE, pp. 393-401

$$\theta = 35.3 \cdot \left[1 - e^{12 \cdot (F-1)}\right]$$ θ = wave propogation direction

$$C = \sqrt{\frac{g \cdot C \cdot T}{2 \cdot \pi} \cdot \tanh\left(\frac{2 \cdot \pi \cdot d}{C \cdot T}\right)} = V \cdot \cos(\theta)$$ (requires trial and error solution for T)

Unconstricted channels, deep water:
(from Gates and Herbich 1977)

$$H_{max} = 1.11 \cdot \left(\frac{K_w \cdot B}{L_e}\right) \cdot \frac{V^2}{2 \cdot g} \cdot \left(2 \cdot N + \frac{3}{2}\right)^{\frac{-1}{3}}$$

distance from the sailing line to channel bank

$$x = \frac{2 \cdot V^2}{g} \cdot \frac{\left(2 \cdot N + \frac{3}{2}\right) \cdot \pi}{\sqrt{3}} \cdot \sin(19.467 \cdot deg)$$

B = ship beam
L_e = the distance from the ship bow back to midship = LWL/2
N = the cusp number = 1, 2, 3...
K_w = coefficient (function of ship waterline length, LWL, and ship speed V)

= $-6.2(V/(LWL)^{1/2}) + 72$ for $V/L^{1/2} < 0.95$
= 1.13 for $V/(LWL)^{1/2} > 1.0$

Canal (from Blaauw et al 1984):

$$H_{max} = A \cdot d \cdot \left(\frac{S}{d}\right)^{-0.33} \left(\frac{V}{\sqrt{g \cdot d}}\right)^{2.67}$$

S = distance from the ship's side to the channel bank
A = a coefficient for ship type and loading
= 0.8 (pushing type)
= 0.35 (empty pushing type and tugboat)
= 0.25 (conventional European inland vessel)

from PIANC 1987 (**navigation channel bank** design): $H_{max} = d \cdot \left(\frac{S}{d}\right)^{-0.33} \cdot \left(\frac{V}{\sqrt{g \cdot d}}\right)^{4}$

ref. Weggel, J., and Sorensen, R., 1986, "Ship Wave Prediction for Port and Channel Design," Proc., Ports '86, American Society of Civil Engineers, NY, pp. 797-814.

dimensionless parameters: $F = \frac{V}{\sqrt{g \cdot d}}$

$F < 0.7$ deep water condition

F = 1, θ = 0

wave height $H_x = \frac{H}{Displ^{\frac{1}{3}}}$

H = max. ship wave height
Displ = ship displacement volume

offset distance (from track) $x_x = \frac{x}{Displ^{\frac{1}{3}}}$

depth $d_x = \frac{d}{Displ^{\frac{1}{3}}}$

block coefficient $c_x = \frac{Displ}{L \cdot B \cdot D}$

length $L_x = \frac{L}{Displ^{\frac{1}{3}}}$

L = ship length
B = beam
D = draft

beam $B_x = \frac{B}{Displ^{\frac{1}{3}}}$ draft $D_x = \frac{D}{Displ^{\frac{1}{3}}}$

model: $H_x = \alpha \cdot x_x^{\ n}$ $n = \beta \cdot d_x^{\ \delta}$

$\log(\alpha) = a + b \cdot \log(d_x) + c \cdot \log(d_x)$ $\alpha = 10^{(a + b \cdot \log(d_x) + c \cdot \log(d_x))}$

$a = \frac{-0.6}{F}$ $b = 0.75 \cdot F^{-1.126}$ $c = 2.6531 \cdot F - 1.95$ $\alpha = 10^{\left[a + 0.43429 \cdot b \cdot \log(d_x) + .1886 \cdot c \cdot \left(\log(d_x)^2\right)\right]}$

$\beta = -0.225 \cdot F^{-0.699}$ $\delta = -0.118 \cdot F^{-0.366}$ for $0.20 < F < 0.55$

$\beta = -0.342$ $\delta = -0.146$ for $0.55 < F < 0.8$

$C_{div} = V \cdot \cos(\theta)$ phase speed of diverging ship waves

$\theta = 35.267 \cdot \left(1 - e^{-12 + 12 \cdot F}\right)$ angle θ in degrees

$C_{div} = \frac{g \cdot T_{div}}{2 \cdot \pi}$ for $F \le 0.7$

$C_{div} = \sqrt{\frac{g \cdot L_{div}}{2 \cdot \pi} \cdot \tanh\left(\frac{2 \cdot \pi \cdot d}{L_{div}}\right)}$ for $F > 0.7$

$T_{div} = \frac{L_{div}}{C_{div}}$

$knots \equiv 6076 \cdot \frac{ft}{hr}$ $tons \equiv 2240 \cdot lbf$ $fathoms \equiv 6 \cdot ft$

Example execution: use characteristics of cruise ship $L := 700\cdot ft \quad B := 80\cdot ft \quad D := 24\cdot ft$

$DWT := 1000\cdot tons$

$$Displ := \frac{DWT}{100\cdot\frac{lbf}{ft^3}} \qquad Displ = 2.24\times 10^4\, ft^3 \qquad Displ^{\frac{1}{3}} = 28.189\, ft$$

$$d := 100\cdot fathoms \qquad d_x := \frac{d}{Displ^{\frac{1}{3}}} \qquad d_x = 21.285$$

$$V := 15\cdot knots \qquad F := \frac{V}{\sqrt{g\cdot d}} \qquad F = 0.182$$

$$a := \frac{-0.6}{F} \qquad a = -3.293$$

$$b := 0.75\cdot F^{-1.125} \qquad b = 5.092$$

$$c := 2.6531\cdot F - 1.95 \qquad c = -1.467$$

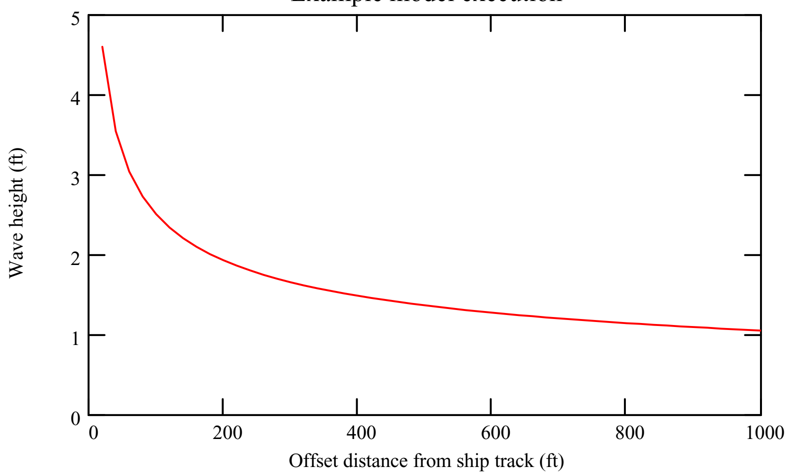
$$\alpha := 10^{\left[a+0.43429\cdot b\cdot \log\left(d_x\right)+.1886\cdot c\cdot\left(\log\left(d_x\right)^2\right)\right]} \qquad \alpha = 0.143$$

$$\beta := -0.225\cdot F^{-0.699} \qquad \delta := -0.118\cdot F^{-0.366} \quad \text{for} \quad 0.20 < F < 0.55$$

$$n := \beta\cdot d_x^{\ \delta} \qquad n = -0.377 \qquad i := 1, 2 .. 100 \qquad x_i := 20\cdot i\cdot ft$$

$$x_{x_i} := \frac{x_i}{Displ^{\frac{1}{3}}} \qquad H_{x_i} := \alpha\cdot\left(x_{x_i}\right)^n \qquad H_i := H_{x_i}\cdot Displ^{\frac{1}{3}}$$

Example model execution



x_i = (ft)	x_{x_i} =	H_{x_i} =	H_i = (ft)
20	0.709	0.163	4.599
40	1.419	0.126	3.541
60	2.128	0.108	3.038
80	2.838	0.097	2.726
100	3.547	0.089	2.505
120	4.257	0.083	2.339
140	4.966	0.078	2.207
160	5.676	0.074	2.098
180	6.385	0.071	2.007
200	7.095	0.068	1.929
220	7.804	0.066	1.861
240	8.514	0.064	1.8
260	9.223	0.062	1.747
280	9.933	0.06	1.699
300	10.642	0.059	1.655
320	11.352	0.057	1.615

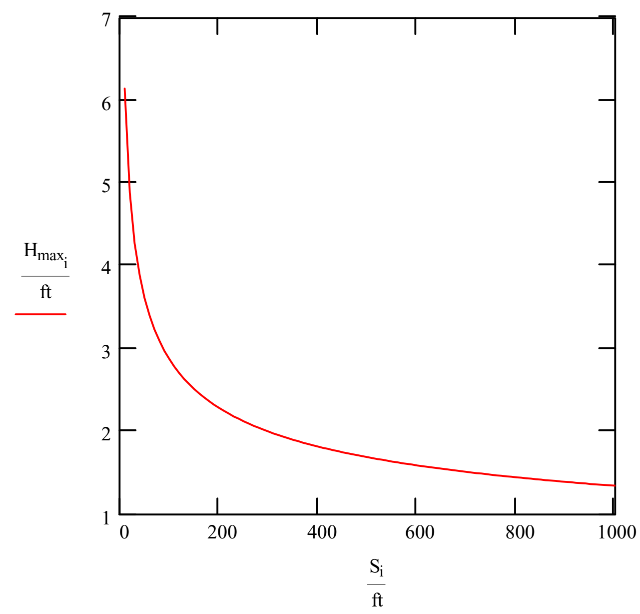
Canal (from Blaauw et al 1984):

S = distance from the ship's side to the channel bank
A = a coefficient for ship type and loading
= 0.8 (pushing type)
= 0.35 (empty pushing type and tugboat)
= 0.25 (conventional European inland vessel)

$A := 0.25$ $\quad S_i := 10 \cdot i \cdot ft$

$$H_{max_i} := A \cdot d \cdot \left(\frac{S_i}{d}\right)^{-0.33} \left(\frac{V}{\sqrt{g \cdot d}}\right)^{2.67}$$

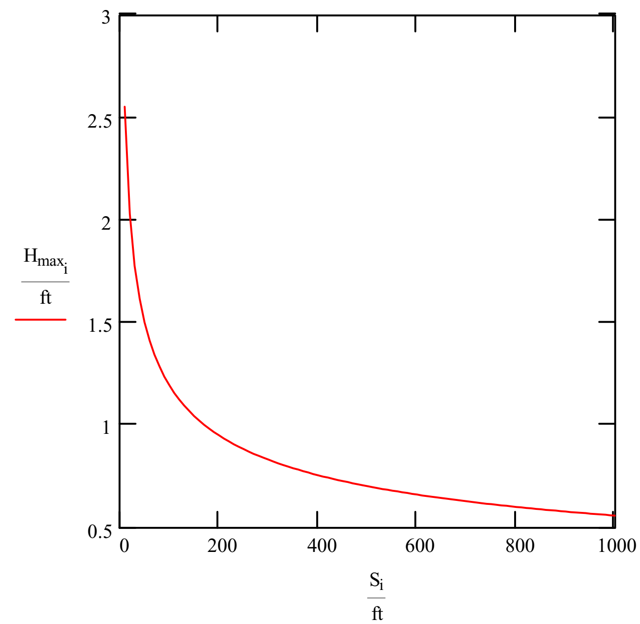
$S_i =$ (ft)	$H_{max_i} =$ (ft)
10	6.146
20	4.89
30	4.277
40	3.89
50	3.614
60	3.403
70	3.234
80	3.095
90	2.977
100	2.875
110	2.786
120	2.707
130	2.636
140	2.573
150	2.515
160	2.462



from PIANC 1987 (**navigation channel bank** design):

$$H_{max_i} := d \cdot \left(\frac{S_i}{d}\right)^{-0.33} \cdot \left(\frac{V}{\sqrt{g \cdot d}}\right)^4$$

$S_i =$ (ft)	$H_{max_i} =$ (ft)
10	2.554
20	2.032
30	1.777
40	1.616
50	1.502
60	1.414
70	1.344
80	1.286
90	1.237
100	1.195
110	1.158
120	1.125
130	1.096
140	1.069
150	1.045
160	1.023



Unconstricted channels, deep water:
(from Gates and Herbich 1977)

$$H_{max} = 1.11 \cdot \left(\frac{K_w \cdot B}{L_e}\right) \cdot \frac{V^2}{2 \cdot g} \cdot \left(2 \cdot N + \frac{3}{2}\right)^{\frac{-1}{3}}$$

distance from the sailing line to channel bank

$$x = \frac{2 \cdot V^2}{g} \cdot \frac{\left(2 \cdot N + \frac{3}{2}\right) \cdot \pi}{\sqrt{3}} \cdot \sin(19.467 \cdot deg)$$

B = ship beam
L_e = the distance from the ship bow back to midship = LWL/2
N = the cusp number = 1, 2, 3...
K_w = coefficient (function of ship waterline length, LWL, and ship speed V)
= $-6.2(V/(g*LWL)^{1/2}) + 72$ for $V/L^{1/2} < 0.95$
= 1.13 for $V/(g*LWL)^{1/2} > 1.0$

$B = 80\,ft$ $\quad L = 700\,ft$ $\quad LWL := L$ $\quad L_e := \frac{LWL}{2}$

$V = 15\,knots$ $\quad \frac{V}{\sqrt{g \cdot LWL}} = 0.169$ $\quad K_w := -6.2 \cdot \frac{V}{\sqrt{g \cdot LWL}} + 72$

$N := 1, 2 .. 20$

$K_w = 70.954$

$$x_N := \frac{2 \cdot V^2}{g} \cdot \frac{\left(2 \cdot N + \frac{3}{2}\right) \cdot \pi}{\sqrt{3}} \cdot \sin(19.467 \cdot deg) \qquad H_{max_N} := 1.11 \cdot \left(\frac{K_w \cdot B}{L_e}\right) \cdot \frac{V^2}{2 \cdot g} \cdot \left(2 \cdot N + \frac{3}{2}\right)^{\frac{-1}{3}}$$

N =	x_N = (ft)	H_{max_N} = (ft)
1	84.291	118.098
2	132.458	101.581
3	180.624	91.604
4	228.791	84.663
5	276.957	79.439
6	325.124	75.305

NOTE: apparent errors in transcription of formulae!

Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants
1506 West 36th Avenue Anchorage, Alaska 99503 (907) 561-1011 Fax (907) 563-4220

Memorandum

To: File — Project No.: 02056.02

From: Jennifer Wilson — Date: October 3, 2002

Re: *Spirit of Adventure Positions and Speeds* document

Project: Glacier Bay National Park and Preserve Vessel Quotas and Operating Requirements Environmental Impact Statement, Appendix F Technical Memorandum Concerning Vessel Wakes

---

The attached document, *Spirit of Adventure Positions and Speeds*, maps the GPS route taken during the site visit to Glacier Bay proper on June 12, 2002. This site visit included a cruise by Sandra Donohue (PN&D Engineers) and Orson Smith, PE. The purpose of the visit was to collect information on the shoreline structure and vessel tracks. The cruise also provided information on different vessel wakes including height, period, and differences due to type of vessel hull.

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots

* speed measured relative to the ground

N5827.30554	W13553.24518	15:33:32	7.56	80.3	1.0
N5827.30876	W13553.26965	15:34:18	7.57	146.6	1.9
N5827.33129	W13553.28606	15:35:03	7.58	11.9	0.2
N5827.33193	W13553.28960	15:35:49	7.60	371.2	4.8
N5827.37925	W13553.36331	15:36:35	7.61	487.7	6.3
N5827.43139	W13553.47982	15:37:21	7.62	486.6	6.3
N5827.46165	W13553.62144	15:38:07	7.64	515.7	6.8
N5827.47323	W13553.78206	15:38:52	7.65	750.7	9.9
N5827.47001	W13554.01798	15:39:37	7.66	1474.9	19.0
N5827.32324	W13554.38716	15:40:23	7.67	1698.6	21.9
N5827.07605	W13554.63596	15:41:09	7.69	1659.5	21.8
N5826.83562	W13554.88283	15:41:54	7.70	1689.8	21.8
N5826.60709	W13555.18507	15:42:40	7.71	1684.3	21.7
N5826.40271	W13555.54234	15:43:26	7.72	1689.0	21.8
N5826.20347	W13555.91216	15:44:12	7.74	1671.8	22.0
N5826.00006	W13556.26557	15:44:57	7.75	1657.4	21.3
N5825.86230	W13556.71489	15:45:43	7.76	1647.8	21.7
N5825.92184	W13557.21990	15:46:28	7.77	1681.1	22.1
N5826.02387	W13557.71074	15:47:13	7.79	1707.9	22.0
N5826.14071	W13558.19869	15:47:59	7.80	1714.5	22.1
N5826.27203	W13558.67537	15:48:45	7.81	1685.1	21.7
N5826.41365	W13559.13049	15:49:31	7.83	1651.8	21.7
N5826.54176	W13559.58818	15:50:16	7.84	1639.8	21.1
N5826.66664	W13600.04491	15:51:02	7.85	1540.7	19.8
N5826.82339	W13600.42535	15:51:48	7.86	1454.2	19.1
N5826.99977	W13600.73402	15:52:33	7.88	1438.2	18.5
N5827.17036	W13601.04719	15:53:19	7.89	1375.3	18.1
N5827.35028	W13601.30919	15:54:04	7.90	1372.2	17.7
N5827.55885	W13601.47399	15:54:50	7.91	1313.6	17.3
N5827.75873	W13601.63074	15:55:35	7.93	1322.5	17.4
N5827.95474	W13601.81098	15:56:20	7.94	1317.5	17.3
N5828.14207	W13602.01923	15:57:05	7.95	1343.9	17.3
N5828.34871	W13602.16922	15:57:51	7.96	1393.5	17.9
N5828.57176	W13602.26996	15:58:37	7.98	1416.8	18.7
N5828.79449	W13602.40096	15:59:22	7.99	1420.8	18.3
N5829.00434	W13602.59762	16:00:08	8.00	1440.1	18.5
N5829.21452	W13602.80651	16:00:54	8.02	1428.0	18.8
N5829.42148	W13603.01894	16:01:39	8.03	1444.9	19.0
N5829.63230	W13603.22880	16:02:24	8.04	1486.5	19.1
N5829.85632	W13603.41612	16:03:10	8.05	1470.0	19.4
N5830.08839	W13603.54583	16:03:55	8.07	1527.3	19.7
N5830.33333	W13603.65237	16:04:41	8.08	1533.1	19.7
N5830.58148	W13603.73799	16:05:27	8.09	1513.1	19.9
N5830.82964	W13603.77339	16:06:12	8.10	1536.5	19.8
N5831.08231	W13603.76599	16:06:58	8.12	1517.4	20.0
N5831.33079	W13603.72157	16:07:43	8.13	1518.9	20.0
N5831.57959	W13603.67844	16:08:28	8.14	1567.4	20.2

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5831.83611	W13603.62952	16:09:14	8.15	1603.3	21.1
N5832.09908	W13603.59218	16:09:59	8.17	1850.2	23.8
N5832.40131	W13603.52427	16:10:45	8.18	1831.1	24.1
N5832.69807	W13603.42610	16:11:30	8.19	1870.8	24.1
N5833.00320	W13603.35014	16:12:16	8.20	1880.0	24.2
N5833.31026	W13603.28062	16:13:02	8.22	1882.9	24.3
N5833.61603	W13603.18663	16:13:48	8.23	1836.3	24.2
N5833.91536	W13603.10971	16:14:33	8.24	1855.4	24.4
N5834.21695	W13603.02055	16:15:18	8.26	1886.0	24.3
N5834.52497	W13602.95038	16:16:04	8.27	1891.2	24.4
N5834.83461	W13602.89373	16:16:50	8.28	1872.4	24.1
N5835.14135	W13602.84127	16:17:36	8.29	1835.1	24.2
N5835.44068	W13602.76724	16:18:21	8.31	1853.2	24.4
N5835.74323	W13602.69643	16:19:06	8.32	1895.9	24.4
N5836.05287	W13602.62594	16:19:52	8.33	1861.5	24.5
N5836.35735	W13602.56447	16:20:37	8.34	1912.7	24.6
N5836.66827	W13602.47273	16:21:23	8.36	1867.6	24.6
N5836.96954	W13602.35783	16:22:08	8.37	1906.9	24.6
N5837.28143	W13602.29474	16:22:54	8.38	1873.0	24.7
N5837.58720	W13602.22297	16:23:39	8.39	1902.4	24.5
N5837.89812	W13602.15570	16:24:25	8.41	1888.5	24.3
N5838.20776	W13602.10903	16:25:11	8.42	1633.5	21.0
N5838.42920	W13602.40128	16:25:57	8.43	282.6	3.7
N5838.46106	W13602.46630	16:26:42	8.45	107.4	1.4
N5838.47748	W13602.47885	16:27:28	8.46	162.4	2.1
N5838.50419	W13602.47949	16:28:14	8.47	67.3	0.9
N5838.51514	W13602.47628	16:28:59	8.48	38.8	0.5
N5838.52093	W13602.47113	16:29:45	8.50	22.1	0.3
N5838.52318	W13602.46565	16:30:31	8.51	14.5	0.2
N5838.52415	W13602.46147	16:31:17	8.52	15.4	0.2
N5838.52318	W13602.45696	16:32:02	8.53	219.7	2.9
N5838.55537	W13602.42542	16:32:47	8.55	319.2	4.1
N5838.60783	W13602.42156	16:33:33	8.56	313.1	4.1
N5838.65837	W13602.44055	16:34:18	8.57	293.4	3.8
N5838.70343	W13602.47370	16:35:04	8.58	254.8	3.3
N5838.74366	W13602.49623	16:35:50	8.60	232.0	3.0
N5838.77778	W13602.52906	16:36:36	8.61	185.7	2.4
N5838.80385	W13602.55964	16:37:21	8.62	117.7	1.5
N5838.81962	W13602.58120	16:38:07	8.64	124.2	1.6
N5838.83668	W13602.60277	16:38:52	8.65	89.7	1.2
N5838.84794	W13602.62111	16:39:37	8.66	239.5	3.1
N5838.88689	W13602.63238	16:40:23	8.67	637.9	8.4
N5838.98796	W13602.57831	16:41:08	8.69	1675.2	22.1
N5839.24867	W13602.40707	16:41:53	8.70	1931.0	24.9
N5839.55830	W13602.27125	16:42:39	8.71	1941.8	25.0
N5839.87180	W13602.38841	16:43:25	8.72	1941.3	25.0
N5840.18014	W13602.54773	16:44:11	8.74	1904.1	25.1
N5840.48205	W13602.70770	16:44:56	8.75	1906.2	25.1
N5840.77366	W13602.92914	16:45:41	8.76	1925.4	25.4

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5841.04821	W13603.23266	16:46:26	8.77	1907.8	25.1
N5841.29251	W13603.61149	16:47:11	8.79	1924.8	25.3
N5841.53906	W13603.99355	16:47:56	8.80	17685.0	25.0
N5843.61541	W13607.91322	16:54:55	8.92	1944.3	25.0
N5843.85359	W13608.32424	16:55:41	8.93	1945.1	25.1
N5844.07536	W13608.76842	16:56:27	8.94	1913.5	25.2
N5844.29487	W13609.20293	16:57:12	8.95	1906.6	25.1
N5844.52822	W13609.60655	16:57:57	8.97	1880.3	24.8
N5844.79215	W13609.91715	16:58:42	8.98	1919.6	24.7
N5845.10339	W13610.01918	16:59:28	8.99	704.6	9.1
N5845.21926	W13610.02305	17:00:14	9.00	55.0	0.7
N5845.21057	W13610.01822	17:01:00	9.02	258.5	3.3
N5845.23729	W13609.95449	17:01:46	9.03	164.6	2.1
N5845.24051	W13609.90267	17:02:32	9.04	20.3	0.3
N5845.24051	W13609.89623	17:03:18	9.06	10.3	0.1
N5845.23890	W13609.89720	17:04:03	9.07	4.1	0.1
N5845.23825	W13609.89687	17:04:49	9.08	2.2	0.0
N5845.23793	W13609.89720	17:05:34	9.09	9.3	0.1
N5845.23890	W13609.89494	17:06:19	9.11	7.8	0.1
N5845.23793	W13609.89655	17:07:05	9.12	7.8	0.1
N5845.23890	W13609.89816	17:07:51	9.13	192.9	2.5
N5845.23954	W13609.95932	17:08:36	9.14	64.3	0.8
N5845.22956	W13609.96608	17:09:22	9.16	1427.5	18.8
N5844.99686	W13610.02626	17:10:07	9.17	1981.3	25.5
N5844.67113	W13610.00888	17:10:53	9.18	1796.8	23.7
N5844.43488	W13610.35103	17:11:38	9.19	1866.7	24.6
N5844.45548	W13610.94133	17:12:23	9.21	1940.0	25.0
N5844.50408	W13611.54901	17:13:09	9.22	1906.1	25.1
N5844.51406	W13612.15283	17:13:54	9.23	1923.3	25.3
N5844.53176	W13612.76147	17:14:39	9.24	1967.1	25.3
N5844.57457	W13613.37945	17:15:25	9.26	1964.1	25.3
N5844.63411	W13613.99132	17:16:11	9.27	1969.8	25.4
N5844.72939	W13614.58806	17:16:57	9.28	1950.6	25.1
N5844.84236	W13615.16677	17:17:43	9.30	1935.0	24.9
N5845.01552	W13615.68143	17:18:29	9.31	1908.0	25.1
N5845.21991	W13616.14041	17:19:14	9.32	1938.6	25.0
N5845.45905	W13616.54693	17:20:00	9.33	1894.4	24.9
N5845.72170	W13616.87008	17:20:45	9.35	1902.5	25.1
N5845.98466	W13617.19710	17:21:30	9.36	1926.0	24.8
N5846.18003	W13617.67796	17:22:16	9.37	1879.4	24.7
N5846.31779	W13618.21162	17:23:01	9.38	1911.0	24.6
N5846.41242	W13618.78969	17:23:47	9.40	1903.4	24.5
N5846.48902	W13619.37516	17:24:33	9.41	1905.5	24.5
N5846.64674	W13619.89754	17:25:19	9.42	1843.5	24.3
N5846.88298	W13620.26415	17:26:04	9.43	1920.8	24.7
N5847.14498	W13620.60468	17:26:50	9.45	1878.7	24.7
N5847.37254	W13621.00798	17:27:35	9.46	1878.9	24.7
N5847.54731	W13621.49979	17:28:20	9.47	1911.2	24.6
N5847.73110	W13621.99192	17:29:06	9.49	1883.9	24.8

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5847.91553	W13622.47247	17:29:51	9.50	1931.8	24.9
N5848.05329	W13623.02511	17:30:37	9.51	1895.6	25.0
N5848.16787	W13623.58483	17:31:22	9.52	1926.5	24.8
N5848.28278	W13624.15485	17:32:08	9.54	1878.3	24.7
N5848.40605	W13624.70170	17:32:53	9.55	1874.2	24.7
N5848.53801	W13625.23954	17:33:38	9.56	1899.6	24.5
N5848.68833	W13625.76836	17:34:24	9.57	1855.8	24.4
N5848.87855	W13626.22927	17:35:09	9.59	1905.1	24.5
N5849.06201	W13626.71980	17:35:55	9.60	1850.1	24.4
N5849.23357	W13627.20517	17:36:40	9.61	1770.4	22.8
N5849.40254	W13627.66318	17:37:26	9.62	1441.6	19.0
N5849.56219	W13628.00179	17:38:11	9.64	392.8	5.1
N5849.59663	W13628.10736	17:38:57	9.65	97.4	1.3
N5849.60307	W13628.13568	17:39:42	9.66	31.5	0.4
N5849.60339	W13628.14566	17:40:28	9.67	12.7	0.2
N5849.60178	W13628.14823	17:41:13	9.69	21.9	0.3
N5849.59824	W13628.14695	17:41:58	9.70	74.0	1.0
N5849.59792	W13628.17044	17:42:44	9.71	777.6	10.0
N5849.68643	W13628.34876	17:43:30	9.73	886.4	11.4
N5849.81196	W13628.49199	17:44:16	9.74	777.1	10.0
N5849.91978	W13628.62459	17:45:02	9.75	275.6	3.6
N5849.94778	W13628.69347	17:45:48	9.76	91.3	1.2
N5849.94457	W13628.72180	17:46:33	9.78	59.3	0.8
N5849.93620	W13628.73145	17:47:18	9.79	248.4	3.2
N5849.93427	W13628.81031	17:48:04	9.80	965.9	12.7
N5849.97482	W13629.10707	17:48:49	9.81	1863.1	24.0
N5850.11902	W13629.62946	17:49:35	9.83	1864.0	24.5
N5850.26546	W13630.14991	17:50:20	9.84	1906.4	24.6
N5850.41996	W13630.67713	17:51:06	9.85	1917.6	24.7
N5850.56866	W13631.21464	17:51:52	9.86	1867.2	24.6
N5850.70610	W13631.74540	17:52:37	9.88	1907.5	24.6
N5850.84740	W13632.28678	17:53:23	9.89	1867.8	24.6
N5850.98580	W13632.81689	17:54:08	9.90	1905.4	24.5
N5851.13160	W13633.35311	17:54:54	9.92	1913.3	24.6
N5851.28449	W13633.88484	17:55:40	9.93	1916.4	24.7
N5851.43577	W13634.41945	17:56:26	9.94	1909.6	24.6
N5851.57803	W13634.96083	17:57:12	9.95	1880.1	24.8
N5851.71482	W13635.49706	17:57:57	9.97	1928.3	24.8
N5851.86352	W13636.03876	17:58:43	9.98	1875.9	24.7
N5852.01351	W13636.56018	17:59:28	9.99	1916.0	24.7
N5852.17219	W13637.08675	18:00:14	10.00	1878.0	24.7
N5852.32733	W13637.60334	18:00:59	10.02	1884.9	24.8
N5852.47957	W13638.12573	18:01:44	10.03	1913.4	24.6
N5852.62731	W13638.66324	18:02:30	10.04	1885.5	24.8
N5852.76571	W13639.20012	18:03:15	10.05	1923.8	24.8
N5852.90251	W13639.75211	18:04:01	10.07	1876.7	24.7
N5853.08372	W13640.23556	18:04:46	10.08	1916.0	24.7
N5853.29100	W13640.69486	18:05:32	10.09	1882.8	24.8
N5853.50214	W13641.13324	18:06:17	10.10	1926.0	24.8

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5853.73581	W13641.54716	18:07:03	10.12	1908.3	25.1
N5853.96048	W13641.97137	18:07:48	10.13	1919.5	25.3
N5854.18546	W13642.40010	18:08:33	10.14	1963.5	25.3
N5854.42300	W13642.82367	18:09:19	10.16	1927.8	25.4
N5854.65313	W13643.24596	18:10:04	10.17	1857.2	23.9
N5854.84271	W13643.70977	18:10:50	10.18	1756.1	22.6
N5854.98272	W13644.19900	18:11:36	10.19	1749.0	22.5
N5855.11501	W13644.69371	18:12:22	10.21	1712.5	22.5
N5855.26113	W13645.16009	18:13:07	10.22	1638.7	21.6
N5855.43526	W13645.55856	18:13:52	10.23	1432.4	18.4
N5855.61905	W13645.84405	18:14:38	10.24	593.5	7.6
N5855.71561	W13645.87173	18:15:24	10.26	297.5	3.8
N5855.76453	W13645.86948	18:16:10	10.27	292.7	3.9
N5855.81249	W13645.86144	18:16:55	10.28	140.5	1.9
N5855.83534	W13645.85468	18:17:40	10.29	75.7	1.0
N5855.84757	W13645.85017	18:18:26	10.31	54.9	0.7
N5855.85658	W13645.84888	18:19:12	10.32	31.9	0.4
N5855.86173	W13645.85081	18:19:57	10.33	13.7	0.2
N5855.86366	W13645.85307	18:20:43	10.35	5.6	0.1
N5855.86431	W13645.85435	18:21:28	10.36	19.8	0.3
N5855.86688	W13645.85822	18:22:14	10.37	21.8	0.3
N5855.86946	W13645.86304	18:23:00	10.38	16.2	0.2
N5855.87075	W13645.86755	18:23:45	10.40	3.9	0.1
N5855.87139	W13645.86755	18:24:30	10.41	11.9	0.2
N5855.86946	W13645.86691	18:25:16	10.42	109.3	1.4
N5855.85497	W13645.84631	18:26:02	10.43	126.3	1.6
N5855.83534	W13645.83311	18:26:48	10.45	201.9	2.7
N5855.81249	W13645.87978	18:27:33	10.46	1312.6	16.9
N5855.74425	W13646.27664	18:28:19	10.47	1786.4	23.0
N5855.82118	W13646.82606	18:29:05	10.48	1798.7	23.2
N5855.91838	W13647.36744	18:29:51	10.50	1778.4	22.9
N5856.05839	W13647.86505	18:30:37	10.51	1743.1	22.5
N5856.29014	W13648.19206	18:31:23	10.52	1672.2	22.0
N5856.53121	W13648.44859	18:32:08	10.54	1727.4	22.7
N5856.68120	W13648.91626	18:32:53	10.55	1890.5	24.9
N5856.82218	W13649.45345	18:33:38	10.56	1897.5	25.0
N5856.96541	W13649.99096	18:34:23	10.57	1943.2	25.0
N5857.08546	W13650.56517	18:35:09	10.59	1897.9	25.0
N5857.19168	W13651.13423	18:35:54	10.60	1912.0	25.2
N5857.29017	W13651.71326	18:36:39	10.61	1963.3	25.3
N5857.40057	W13652.30163	18:37:25	10.62	1890.1	24.9
N5857.53382	W13652.84623	18:38:10	10.64	1906.8	25.1
N5857.76782	W13653.25114	18:38:55	10.65	1944.0	25.0
N5858.01404	W13653.64671	18:39:41	10.66	1945.3	25.1
N5858.26446	W13654.03295	18:40:27	10.67	1901.5	25.0
N5858.51004	W13654.40856	18:41:12	10.69	1898.6	25.0
N5858.76270	W13654.76455	18:41:57	10.70	1948.8	25.1
N5859.02052	W13655.13405	18:42:43	10.71	1890.6	24.9
N5859.24679	W13655.54796	18:43:28	10.72	1935.8	24.9

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5859.46051	W13656.00598	18:44:14	10.74	1942.3	25.0
N5859.66521	W13656.48202	18:45:00	10.75	1893.9	24.9
N5859.86895	W13656.93939	18:45:45	10.76	1932.1	24.9
N5900.11293	W13657.33464	18:46:31	10.78	1925.7	24.8
N5900.36623	W13657.70382	18:47:17	10.79	1878.1	24.7
N5900.61761	W13658.05240	18:48:02	10.80	1931.9	24.9
N5900.90150	W13658.32952	18:48:48	10.81	1861.9	24.5
N5901.17476	W13658.59796	18:49:33	10.83	1928.2	24.8
N5901.45221	W13658.89633	18:50:19	10.84	1905.5	24.5
N5901.70906	W13659.24523	18:51:05	10.85	1750.7	22.5
N5901.92728	W13659.61022	18:51:51	10.86	730.6	9.4
N5902.03607	W13659.70936	18:52:37	10.88	441.4	5.7
N5902.09626	W13659.78822	18:53:23	10.89	334.0	4.3
N5902.14229	W13659.84647	18:54:09	10.90	271.7	3.6
N5902.17351	W13659.90859	18:54:54	10.92	337.8	4.4
N5902.21953	W13659.96910	18:55:39	10.93	335.4	4.3
N5902.26942	W13700.01481	18:56:25	10.94	1195.4	15.7
N5902.37821	W13700.33313	18:57:10	10.95	1904.3	25.1
N5902.44935	W13700.92601	18:57:55	10.97	1363.1	17.6
N5902.48861	W13701.35505	18:58:41	10.98	488.6	6.3
N5902.48572	W13701.51116	18:59:27	10.99	538.8	7.1
N5902.47606	W13701.68239	19:00:12	11.00	656.4	8.5
N5902.48636	W13701.89128	19:00:58	11.02	370.7	4.8
N5902.49312	W13702.00908	19:01:44	11.03	414.1	5.3
N5902.47413	W13702.13622	19:02:30	11.04	540.7	7.0
N5902.47316	W13702.30906	19:03:16	11.05	296.1	3.8
N5902.48024	W13702.40273	19:04:02	11.07	197.8	2.5
N5902.48636	W13702.46485	19:04:48	11.08	328.8	4.3
N5902.46351	W13702.56012	19:05:33	11.09	202.0	2.6
N5902.45932	W13702.62417	19:06:19	11.11	169.1	2.2
N5902.44420	W13702.66955	19:07:05	11.12	204.3	2.7
N5902.42070	W13702.71622	19:07:50	11.13	134.7	1.7
N5902.39978	W13702.73038	19:08:36	11.14	38.0	0.5
N5902.39559	W13702.72137	19:09:21	11.16	52.7	0.7
N5902.39302	W13702.70528	19:10:06	11.17	41.5	0.5
N5902.39141	W13702.69240	19:10:52	11.18	37.2	0.5
N5902.39141	W13702.68050	19:11:38	11.19	34.3	0.5
N5902.39109	W13702.66955	19:12:23	11.21	38.1	0.5
N5902.38980	W13702.65764	19:13:08	11.22	39.3	0.5
N5902.38980	W13702.64509	19:13:54	11.23	4.4	0.1
N5902.38916	W13702.64445	19:14:39	11.24	9.3	0.1
N5902.38883	W13702.64734	19:15:25	11.26	13.3	0.2
N5902.38723	W13702.64445	19:16:11	11.27	42.7	0.5
N5902.38304	W13702.63350	19:16:57	11.28	35.6	0.5
N5902.38143	W13702.62256	19:17:42	11.30	76.7	1.0
N5902.37435	W13702.60228	19:18:28	11.31	41.6	0.5
N5902.36791	W13702.59778	19:19:13	11.32	26.0	0.3
N5902.36405	W13702.59424	19:19:59	11.33	18.2	0.2
N5902.36373	W13702.58844	19:20:45	11.35	19.7	0.3

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5902.36630	W13702.58458	19:21:30	11.36	30.0	0.4
N5902.37113	W13702.58265	19:22:16	11.37	6.3	0.1
N5902.37145	W13702.58072	19:23:02	11.38	4.4	0.1
N5902.37210	W13702.58136	19:23:48	11.40	19.8	0.3
N5902.36952	W13702.57750	19:24:34	11.41	17.0	0.2
N5902.36824	W13702.57267	19:25:19	11.42	21.7	0.3
N5902.36470	W13702.57170	19:26:05	11.43	15.6	0.2
N5902.36309	W13702.57557	19:26:50	11.45	18.6	0.2
N5902.36598	W13702.57750	19:27:36	11.46	37.6	0.5
N5902.36437	W13702.56591	19:28:21	11.47	40.7	0.5
N5902.36341	W13702.55304	19:29:07	11.49	42.9	0.6
N5902.36148	W13702.53984	19:29:52	11.50	49.3	0.6
N5902.35987	W13702.52439	19:30:38	11.51	61.9	0.8
N5902.35568	W13702.50637	19:31:23	11.52	42.1	0.5
N5902.36051	W13702.51602	19:32:09	11.54	11.7	0.2
N5902.36148	W13702.51280	19:32:55	11.55	15.2	0.2
N5902.36019	W13702.50862	19:33:40	11.56	22.0	0.3
N5902.35922	W13702.50186	19:34:26	11.57	29.5	0.4
N5902.35568	W13702.49542	19:35:11	11.59	36.8	0.5
N5902.35246	W13702.48544	19:35:56	11.60	23.1	0.3
N5902.35246	W13702.47804	19:36:42	11.61	41.4	0.5
N5902.35085	W13702.46517	19:37:27	11.62	66.7	0.9
N5902.34281	W13702.45068	19:38:13	11.64	28.8	0.4
N5902.34538	W13702.44296	19:38:58	11.65	31.8	0.4
N5902.34377	W13702.43330	19:39:44	11.66	25.2	0.5
N5902.34345	W13702.42526	19:40:12	11.67	23.3	0.3
N5902.34152	W13702.41882	19:40:57	11.68	24.5	0.3
N5902.34216	W13702.41109	19:41:42	11.70	27.3	0.4
N5902.34184	W13702.40240	19:42:28	11.71	16.2	0.2
N5902.34216	W13702.39725	19:43:13	11.72	12.7	0.2
N5902.34281	W13702.39339	19:43:59	11.73	28.0	0.4
N5902.34023	W13702.38599	19:44:45	11.75	23.2	0.3
N5902.33991	W13702.37859	19:45:30	11.76	31.8	0.4
N5902.33895	W13702.36861	19:46:16	11.77	27.5	0.4
N5902.33830	W13702.35992	19:47:01	11.78	74.3	1.0
N5902.34377	W13702.33867	19:47:47	11.80	351.1	4.5
N5902.36244	W13702.23246	19:48:33	11.81	468.3	6.0
N5902.36405	W13702.08279	19:49:19	11.82	624.1	8.0
N5902.35118	W13701.88484	19:50:05	11.83	677.8	8.7
N5902.40074	W13701.69076	19:50:51	11.85	911.6	11.7
N5902.49441	W13701.46320	19:51:37	11.86	967.2	12.7
N5902.53367	W13701.16354	19:52:22	11.87	1850.5	24.4
N5902.42810	W13700.60865	19:53:07	11.89	1831.1	23.6
N5902.22983	W13700.16802	19:53:53	11.90	627.2	8.1
N5902.16449	W13700.01288	19:54:39	11.91	623.8	8.0
N5902.10237	W13659.85420	19:55:25	11.92	397.3	5.2
N5902.05410	W13659.76858	19:56:10	11.94	350.9	4.6
N5902.01740	W13659.68200	19:56:55	11.95	355.5	4.7
N5901.99101	W13659.58061	19:57:40	11.96	267.7	3.4

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5901.98264	W13659.49661	19:58:26	11.97	357.4	4.7
N5901.96526	W13659.38749	19:59:11	11.99	369.9	4.9
N5901.93629	W13659.28353	19:59:56	12.00	460.6	5.9
N5901.87771	W13659.19019	20:00:42	12.01	676.5	8.7
N5901.78920	W13659.05919	20:01:28	12.02	1019.7	13.1
N5901.64661	W13658.88764	20:02:14	12.04	1131.5	14.9
N5901.46862	W13658.78207	20:02:59	12.05	1418.6	18.3
N5901.24782	W13658.63562	20:03:45	12.06	1894.2	24.9
N5900.94205	W13658.51975	20:04:30	12.08	1939.6	25.5
N5900.66621	W13658.20850	20:05:15	12.09	1996.0	25.7
N5900.38651	W13657.87473	20:06:01	12.10	2001.7	25.8
N5900.10842	W13657.53258	20:06:47	12.11	1955.7	25.8
N5859.82936	W13657.22199	20:07:32	12.13	2006.7	25.8
N5859.55159	W13656.87598	20:08:18	12.14	1987.4	25.6
N5859.28284	W13656.51485	20:09:04	12.15	1955.5	25.7
N5859.01054	W13656.18268	20:09:49	12.16	2010.3	25.9
N5858.71732	W13655.88625	20:10:35	12.18	1990.2	25.6
N5858.46433	W13655.48327	20:11:21	12.19	1930.8	25.4
N5858.21199	W13655.10926	20:12:06	12.20	1992.9	25.7
N5857.93583	W13654.76680	20:12:52	12.21	1968.4	25.4
N5857.66192	W13654.43206	20:13:38	12.23	1983.6	25.5
N5857.40508	W13654.04196	20:14:24	12.24	1992.0	25.7
N5857.11540	W13653.74520	20:15:10	12.25	1975.7	25.4
N5856.81767	W13653.49286	20:15:56	12.27	1922.5	25.3
N5856.52252	W13653.27302	20:16:41	12.28	1950.2	25.1
N5856.20516	W13653.18290	20:17:27	12.29	1908.6	25.1
N5855.89134	W13653.19706	20:18:12	12.30	1873.1	24.7
N5855.64319	W13653.55079	20:18:57	12.32	1938.3	25.0
N5855.42464	W13654.00044	20:19:43	12.33	1922.3	24.8
N5855.19644	W13654.42433	20:20:29	12.34	1920.0	24.7
N5854.92060	W13654.72206	20:21:15	12.35	1907.1	25.1
N5854.66053	W13655.06163	20:22:00	12.37	1940.0	25.0
N5854.40175	W13655.42308	20:22:46	12.38	1899.3	25.0
N5854.16261	W13655.81222	20:23:31	12.39	1914.4	25.2
N5853.97432	W13656.30081	20:24:16	12.40	1390.4	17.9
N5853.84042	W13656.65969	20:25:02	12.42	78.6	1.0
N5853.83334	W13656.68061	20:25:47	12.43	33.4	0.4
N5853.82787	W13656.68157	20:26:32	12.44	295.8	3.8
N5853.83817	W13656.58952	20:27:18	12.46	470.2	6.1
N5853.86553	W13656.44951	20:28:04	12.47	476.2	6.1
N5853.89997	W13656.31336	20:28:50	12.48	366.2	4.7
N5853.93086	W13656.21326	20:29:36	12.49	415.7	5.4
N5853.97689	W13656.11541	20:30:22	12.51	859.4	11.1
N5854.06347	W13655.89912	20:31:08	12.52	1845.5	23.8
N5854.25112	W13655.43724	20:31:54	12.53	1918.1	24.7
N5854.20252	W13654.83375	20:32:40	12.54	1979.5	25.5
N5854.05704	W13654.26984	20:33:26	12.56	1977.7	25.5
N5853.91670	W13653.70175	20:34:12	12.57	1985.3	25.6
N5853.77186	W13653.13526	20:34:58	12.58	2000.3	25.8

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5853.61962	W13652.57071	20:35:44	12.60	1949.0	25.7
N5853.51212	W13651.98621	20:36:29	12.61	1987.4	25.6
N5853.42715	W13651.37531	20:37:15	12.62	1950.3	25.7
N5853.33928	W13650.77825	20:38:00	12.63	1934.6	25.5
N5853.16483	W13650.26326	20:38:45	12.65	2001.6	25.8
N5852.91345	W13649.85192	20:39:31	12.66	1875.5	24.7
N5852.66787	W13649.49079	20:40:16	12.67	815.4	10.5
N5852.56165	W13649.33243	20:41:02	12.68	310.5	4.1
N5852.52335	W13649.26709	20:41:47	12.70	387.1	5.0
N5852.49760	W13649.15444	20:42:33	12.71	366.2	4.8
N5852.50758	W13649.03953	20:43:18	12.72	360.4	4.6
N5852.53848	W13648.94168	20:44:04	12.73	507.8	6.7
N5852.58804	W13648.81165	20:44:49	12.75	961.2	12.4
N5852.71647	W13648.63334	20:45:35	12.76	1795.0	23.1
N5852.91635	W13648.21298	20:46:21	12.77	1981.1	25.5
N5852.98555	W13647.59693	20:47:07	12.79	1980.3	25.5
N5852.98780	W13646.96672	20:47:53	12.80	1952.2	25.7
N5852.96205	W13646.34745	20:48:38	12.81	1988.3	25.6
N5852.91570	W13645.72110	20:49:24	12.82	1994.1	25.7
N5852.86002	W13645.09572	20:50:10	12.84	1992.8	25.7
N5852.73288	W13644.51121	20:50:56	12.85	2001.5	25.8
N5852.55553	W13643.97466	20:51:42	12.86	1995.9	25.7
N5852.41359	W13643.40206	20:52:28	12.87	1918.1	25.3
N5852.29965	W13642.83301	20:53:13	12.89	1977.6	25.5
N5852.20277	W13642.23241	20:53:59	12.90	1991.7	25.7
N5852.09945	W13641.63116	20:54:45	12.91	1954.0	25.7
N5851.99678	W13641.04215	20:55:30	12.93	2001.1	25.8
N5851.88541	W13640.44316	20:56:16	12.94	1951.6	25.7
N5851.78113	W13639.85608	20:57:01	12.95	2000.2	25.8
N5851.67266	W13639.25548	20:57:47	12.96	1964.9	25.9
N5851.56516	W13638.66614	20:58:32	12.98	1965.6	25.9
N5851.45186	W13638.08067	20:59:17	12.99	2007.2	25.9
N5851.33824	W13637.48136	21:00:03	13.00	1959.4	25.8
N5851.23363	W13636.89202	21:00:48	13.01	2001.0	25.8
N5851.12839	W13636.28917	21:01:34	13.03	1941.4	25.6
N5851.01251	W13635.71399	21:02:19	13.04	1995.0	25.7
N5850.83259	W13635.18356	21:03:05	13.05	1961.0	25.8
N5850.64913	W13634.67083	21:03:50	13.06	1960.1	25.8
N5850.46406	W13634.16067	21:04:35	13.08	2008.2	25.9
N5850.27737	W13633.63410	21:05:21	13.09	1959.6	25.8
N5850.07814	W13633.14455	21:06:06	13.10	2006.7	25.8
N5849.85412	W13632.67623	21:06:52	13.11	1977.2	26.0
N5849.64169	W13632.20052	21:07:37	13.13	2012.4	25.9
N5849.42411	W13631.71868	21:08:23	13.14	1959.8	25.8
N5849.18142	W13631.30895	21:09:08	13.15	1979.7	26.1
N5848.94228	W13630.88216	21:09:53	13.16	2031.5	26.2
N5848.71601	W13630.40741	21:10:39	13.18	1976.7	26.0
N5848.49875	W13629.94038	21:11:24	13.19	2031.6	26.2
N5848.27730	W13629.45726	21:12:10	13.20	2040.8	26.3

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5848.05103	W13628.97865	21:12:56	13.22	2048.9	26.4
N5847.82895	W13628.48941	21:13:42	13.23	2015.1	26.5
N5847.62006	W13627.99277	21:14:27	13.24	2013.6	26.5
N5847.40795	W13627.50193	21:15:12	13.25	2045.7	26.3
N5847.14627	W13627.09380	21:15:58	13.27	2065.6	26.6
N5846.85659	W13626.75134	21:16:44	13.28	2055.1	26.5
N5846.57914	W13626.37894	21:17:30	13.29	2011.3	26.5
N5846.31457	W13625.99592	21:18:15	13.30	2071.0	26.7
N5846.01009	W13625.70142	21:19:01	13.32	2009.4	26.5
N5845.69916	W13625.48544	21:19:46	13.33	1940.3	25.0
N5845.38696	W13625.61290	21:20:32	13.34	1940.5	25.5
N5845.21283	W13626.12853	21:21:17	13.35	2016.6	26.0
N5845.09116	W13626.72334	21:22:03	13.37	1960.2	25.8
N5844.97980	W13627.30656	21:22:48	13.38	2003.4	25.8
N5844.88452	W13627.91456	21:23:34	13.39	2012.9	25.9
N5844.78668	W13628.52417	21:24:20	13.41	1974.3	26.0
N5844.65375	W13629.09516	21:25:05	13.42	1950.6	25.1
N5844.48670	W13629.62302	21:25:51	13.43	700.6	9.2
N5844.44325	W13629.82869	21:26:36	13.44	299.2	3.9
N5844.42651	W13629.91785	21:27:22	13.46	254.6	3.3
N5844.41106	W13629.99284	21:28:08	13.47	78.1	1.0
N5844.40655	W13630.01602	21:28:53	13.48	18.3	0.2
N5844.40655	W13630.02181	21:29:39	13.49	2.8	0.0
N5844.40688	W13630.02117	21:30:24	13.51	2.2	0.0
N5844.40655	W13630.02085	21:31:10	13.52	9.0	0.1
N5844.40720	W13630.02342	21:31:55	13.53	7.1	0.1
N5844.40816	W13630.02213	21:32:41	13.54	26.6	0.3
N5844.40945	W13630.01409	21:33:26	13.56	245.4	3.2
N5844.42329	W13629.94102	21:34:12	13.57	105.0	1.4
N5844.43263	W13629.91302	21:34:57	13.58	120.7	1.6
N5844.42007	W13629.88341	21:35:42	13.60	421.3	5.4
N5844.43166	W13629.75177	21:36:28	13.61	1020.6	13.4
N5844.51180	W13629.46756	21:37:13	13.62	1867.2	24.1
N5844.62800	W13628.91974	21:37:59	13.63	1608.5	21.2
N5844.70074	W13628.42954	21:38:44	13.65	120.6	1.6
N5844.70685	W13628.39317	21:39:29	13.66	326.4	4.3
N5844.68336	W13628.48619	21:40:14	13.67	1666.7	21.5
N5844.62220	W13629.00118	21:41:00	13.68	453.1	5.8
N5844.60289	W13629.13990	21:41:46	13.70	166.0	2.2
N5844.57650	W13629.12638	21:42:31	13.71	1596.7	20.6
N5844.61190	W13628.62492	21:43:17	13.72	1896.4	24.4
N5844.61931	W13628.02399	21:44:03	13.73	1853.7	23.9
N5844.53144	W13627.46137	21:44:49	13.75	1859.6	24.5
N5844.39271	W13626.93609	21:45:34	13.76	1919.7	24.7
N5844.23114	W13626.41338	21:46:20	13.77	1946.4	25.1
N5844.04381	W13625.91320	21:47:06	13.79	1905.4	25.1
N5843.86132	W13625.42236	21:47:51	13.80	1949.9	25.1
N5843.70650	W13624.88130	21:48:37	13.81	1955.6	25.2
N5843.57325	W13624.31740	21:49:23	13.82	1970.6	25.4

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5843.44257	W13623.74609	21:50:09	13.84	1928.6	25.4
N5843.25621	W13623.25170	21:50:54	13.85	2001.9	25.8
N5843.01030	W13622.83006	21:51:40	13.86	1999.9	25.8
N5842.75571	W13622.42901	21:52:26	13.87	2008.7	25.9
N5842.49725	W13622.03280	21:53:12	13.89	2015.2	26.0
N5842.24137	W13621.62725	21:53:58	13.90	1978.7	26.1
N5841.97808	W13621.25903	21:54:43	13.91	2002.4	25.8
N5841.65815	W13621.10872	21:55:29	13.92	1250.0	16.5
N5841.45666	W13621.03019	21:56:14	13.94	501.8	6.5
N5841.37459	W13621.01345	21:57:00	13.95	227.1	3.0
N5841.33725	W13621.01442	21:57:45	13.96	30.0	0.4
N5841.33242	W13621.01249	21:58:31	13.98	27.5	0.4
N5841.32920	W13621.00637	21:59:17	13.99	50.2	0.6
N5841.32373	W13620.99446	22:00:03	14.00	64.6	0.9
N5841.31697	W13620.97869	22:00:48	14.01	192.6	2.5
N5841.28768	W13620.95552	22:01:33	14.03	210.1	2.7
N5841.25582	W13620.92977	22:02:19	14.04	860.2	11.1
N5841.11677	W13620.87956	22:03:05	14.05	937.6	12.3
N5840.97612	W13621.00122	22:03:50	14.06	769.5	9.9
N5840.85703	W13621.08362	22:04:36	14.08	1297.5	17.1
N5840.75403	W13620.72409	22:05:21	14.09	1962.6	25.3
N5840.70414	W13620.11062	22:06:07	14.10	1978.4	25.5
N5840.67356	W13619.48749	22:06:53	14.11	1982.9	25.5
N5840.64588	W13618.86243	22:07:39	14.13	1994.4	25.7
N5840.60372	W13618.23672	22:08:25	14.14	2002.2	25.8
N5840.56188	W13617.60844	22:09:11	14.15	1956.4	25.8
N5840.52325	W13616.99400	22:09:56	14.17	2021.0	26.0
N5840.49107	W13616.35767	22:10:42	14.18	2008.2	25.9
N5840.46178	W13615.72489	22:11:28	14.19	1934.7	25.5
N5840.41414	W13615.11978	22:12:13	14.20	1204.5	15.9
N5840.37069	W13614.74803	22:12:58	14.22	430.5	5.5
N5840.36554	W13614.61220	22:13:44	14.23	376.5	4.8
N5840.39451	W13614.50695	22:14:30	14.24	389.7	5.0
N5840.44697	W13614.43614	22:15:16	14.25	650.4	8.4
N5840.54771	W13614.36694	22:16:02	14.27	1546.5	20.4
N5840.74824	W13614.06599	22:16:47	14.28	1963.2	25.3
N5840.80746	W13613.45542	22:17:33	14.29	2014.4	25.9
N5840.66198	W13612.88282	22:18:19	14.31	1999.2	26.3
N5840.43699	W13612.42158	22:19:04	14.32	2037.2	26.2
N5840.18433	W13611.99833	22:19:50	14.33	1988.3	26.2
N5839.93134	W13611.59986	22:20:35	14.34	2019.9	26.0
N5839.68222	W13611.17725	22:21:21	14.36	1951.4	25.7
N5839.43631	W13610.78072	22:22:06	14.37	1968.3	25.9
N5839.20007	W13610.35521	22:22:51	14.38	1922.8	25.3
N5839.00662	W13609.87434	22:23:36	14.39	1963.6	25.3
N5838.81447	W13609.37545	22:24:22	14.41	1979.1	25.5
N5838.59045	W13608.92162	22:25:08	14.42	1985.1	25.6
N5838.34584	W13608.50610	22:25:54	14.43	1941.3	25.6
N5838.10926	W13608.09411	22:26:39	14.44	1922.9	25.3

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5837.87302	W13607.69017	22:27:24	14.46	1988.8	25.6
N5837.61971	W13607.29266	22:28:10	14.47	1989.3	25.6
N5837.36189	W13606.90578	22:28:56	14.48	1964.4	25.9
N5837.10601	W13606.52695	22:29:41	14.49	2025.6	26.1
N5836.83918	W13606.14393	22:30:27	14.51	2015.8	26.0
N5836.57139	W13605.76863	22:31:13	14.52	2001.7	26.4
N5836.30167	W13605.40621	22:31:58	14.53	2020.2	26.0
N5836.02519	W13605.05248	22:32:44	14.55	2046.6	26.4
N5835.73905	W13604.71227	22:33:30	14.56	1078.7	26.6
N5835.58649	W13604.53846	22:33:54	14.57	4898.9	24.8
N5834.92505	W13603.65559	22:35:51	14.60	1809.1	23.8
N5834.66917	W13603.36430	22:36:36	14.61	1796.5	23.7
N5834.39398	W13603.15799	22:37:21	14.62	1860.7	24.0
N5834.09271	W13603.05499	22:38:07	14.64	1884.6	24.3
N5833.78275	W13603.05692	22:38:53	14.65	1775.7	23.4
N5833.49147	W13603.09747	22:39:38	14.66	1144.9	15.1
N5833.30317	W13603.09780	22:40:23	14.67	1104.8	14.5
N5833.12164	W13603.11325	22:41:08	14.69	1112.1	14.3
N5832.93947	W13603.14447	22:41:54	14.70	1074.4	14.1
N5832.76534	W13603.20208	22:42:39	14.71	1095.6	14.1
N5832.59057	W13603.28609	22:43:25	14.72	1043.5	13.7
N5832.42320	W13603.35883	22:44:10	14.74	1029.6	13.3
N5832.25615	W13603.41194	22:44:56	14.75	1156.0	14.9
N5832.06979	W13603.48403	22:45:42	14.76	1479.7	19.1
N5831.82968	W13603.55999	22:46:28	14.77	1459.8	18.8
N5831.59278	W13603.63467	22:47:14	14.79	1435.0	18.9
N5831.35686	W13603.64690	22:47:59	14.80	1450.4	18.7
N5831.11835	W13603.63885	22:48:45	14.81	1361.9	17.9
N5830.89595	W13603.68971	22:49:30	14.83	1351.2	17.8
N5830.67386	W13603.70451	22:50:15	14.84	1327.4	17.5
N5830.45885	W13603.63209	22:51:00	14.85	1371.9	17.7
N5830.24256	W13603.50914	22:51:46	14.86	1388.8	17.9
N5830.02240	W13603.39263	22:52:32	14.88	1409.7	18.2
N5829.79806	W13603.28062	22:53:18	14.89	1433.3	18.5
N5829.57533	W13603.13288	22:54:04	14.90	1429.4	18.8
N5829.35679	W13602.96712	22:54:49	14.91	1422.8	18.7
N5829.14178	W13602.79042	22:55:34	14.93	1451.8	18.7
N5828.91229	W13602.66424	22:56:20	14.94	1405.5	18.5
N5828.70083	W13602.48561	22:57:05	14.95	1438.1	18.5
N5828.47359	W13602.36008	22:57:51	14.96	1439.6	19.0
N5828.25054	W13602.20816	22:58:36	14.98	1480.2	19.1
N5828.02330	W13602.04111	22:59:22	14.99	1443.3	19.0
N5827.80347	W13601.86988	23:00:07	15.00	1459.3	19.2
N5827.62837	W13601.55606	23:00:52	15.01	1469.7	19.4
N5827.46969	W13601.20748	23:01:37	15.03	1493.8	19.2
N5827.29685	W13600.87371	23:02:23	15.04	1513.4	19.5
N5827.11403	W13600.55088	23:03:09	15.05	1491.6	19.6
N5826.94666	W13600.20809	23:03:54	15.07	1522.7	19.6
N5826.79764	W13559.82346	23:04:40	15.08	1492.9	19.7

GPS Way Point Log
Cruise of Spirit of Adventure - 6-12-02

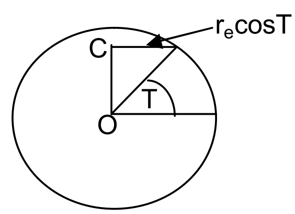
LATITUDE	LONGITUDE	GMT	DEC TIME local	DISTANCE feet	SPEED * knots
N5826.67018	W13559.42242	23:05:25	15.09	1516.3	19.5
N5826.55463	W13559.00013	23:06:11	15.10	1510.6	19.9
N5826.42975	W13558.58975	23:06:56	15.12	1556.4	20.0
N5826.31227	W13558.15524	23:07:42	15.13	1544.7	20.3
N5826.20573	W13557.71460	23:08:27	15.14	1618.0	20.8
N5826.11013	W13557.24017	23:09:13	15.15	1604.9	20.7
N5825.99973	W13556.78216	23:09:59	15.17	1519.6	20.0
N5825.97495	W13556.30709	23:10:44	15.18	1699.2	21.9
N5826.17419	W13555.93276	23:11:30	15.19	1693.4	22.3
N5826.40432	W13555.63310	23:12:15	15.20	1684.6	21.7
N5826.63156	W13555.33023	23:13:01	15.22	1613.8	21.2
N5826.85429	W13555.05439	23:13:46	15.23	1635.2	21.5
N5827.08989	W13554.80655	23:14:31	15.24	1567.0	20.2
N5827.27593	W13554.46570	23:15:17	15.25	1053.6	13.9
N5827.34449	W13554.16153	23:16:02	15.27	957.5	12.3
N5827.40596	W13553.88441	23:16:48	15.28	647.3	8.5
N5827.44716	W13553.69676	23:17:33	15.29	455.2	5.9
N5827.47613	W13553.56480	23:18:19	15.31	295.3	3.9
N5827.46519	W13553.47435	23:19:04	15.32	363.1	4.7
N5827.41465	W13553.41352	23:19:50	15.33	322.4	4.2
N5827.36991	W13553.35912	23:20:36	15.34	284.8	3.7
N5827.33258	W13553.30505	23:21:21	15.36	134.9	1.8
N5827.31874	W13553.27190	23:22:06	15.37	45.1	0.6
N5827.31842	W13553.25774	23:22:52	15.38	41.1	0.5
N5827.32002	W13553.24518	23:23:38	15.39	2.8	0.0
N5827.31970	W13553.24454	23:24:24	15.41	3.1	0.0
N5827.31970	W13553.24358	23:25:09	15.42	15.5	0.2
N5827.32002	W13553.24840	23:25:51	15.43	26865009.7	-286.5

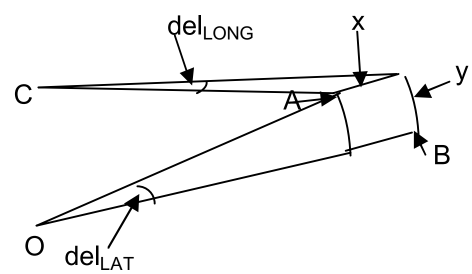
Approximate Distance given Latitude, Longitude - example calculation

Point A   Nome Municipl Airport
Point B   NOAA buoy in Norton sound

decimal latitude of A =	64.517			
decimal longitude of A =	165.45	$x=(Pi/180)del_{LONG}*CosT*r_e$	654.41	miles
		$y=(Pi/180)del_{LAT}*r_e$	513.59	miles
decimal latitude of B =	57.083	distance= $(x^2 + y^2)^{0.5}$	831.88	miles
decimal longitude of B =	177.73			

r_e =	3958.76	miles
T =	59	deg





Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants
1506 West 36th Avenue Anchorage, Alaska 99503 (907) 561-1011 Fax (907) 563-4220

Memorandum

To: File — Project No.: 02056.02

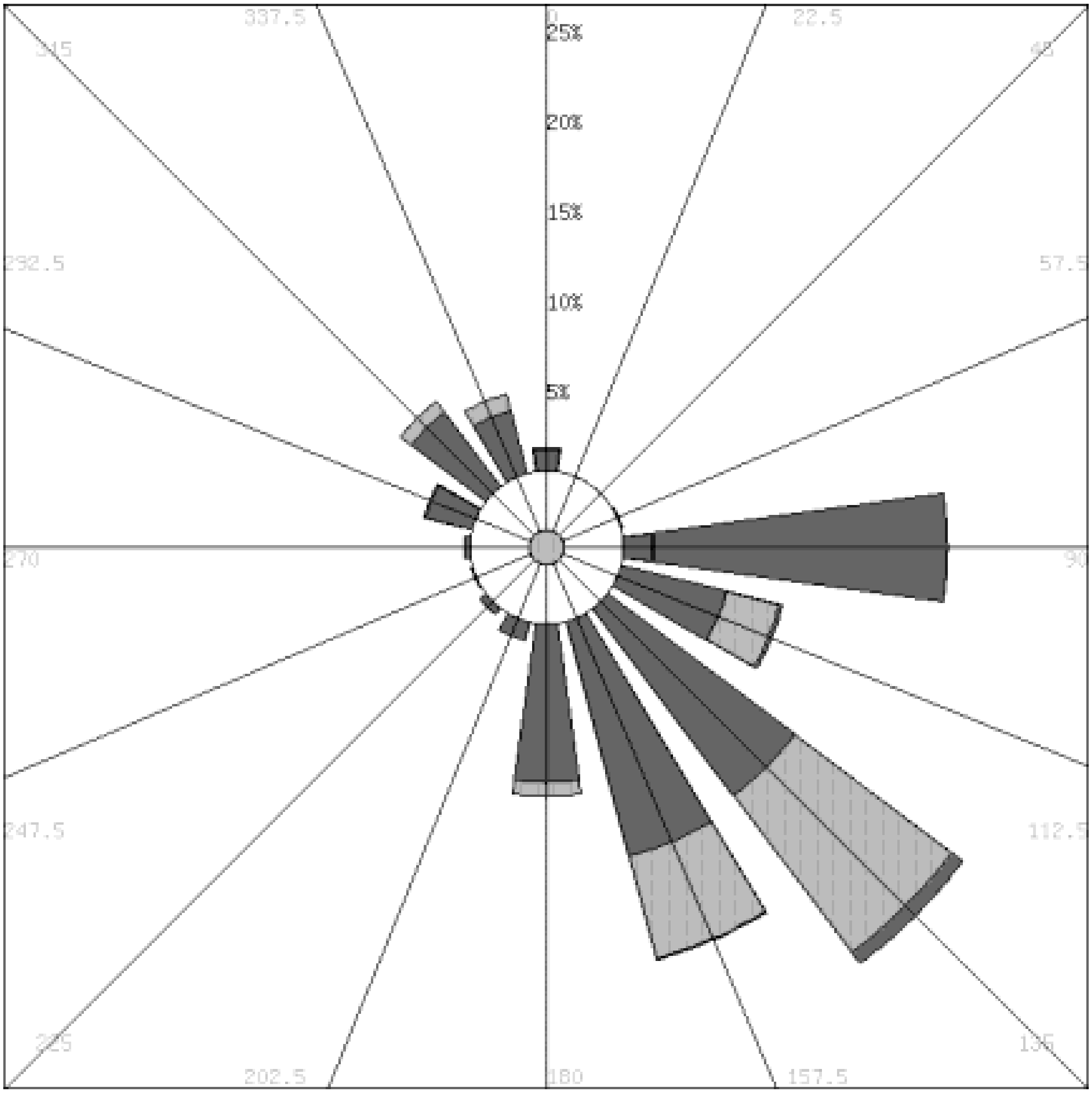
From: Jennifer Wilson — Date: October 3, 2002

Re: *Wind Summaries for Sitka, Ketchikan, Juneau, and Cordova (1987-1999)*

Project: Glacier Bay National Park and Preserve Vessel Quotas and Operating Requirements Environmental Impact Statement, Appendix F Technical Memorandum

---

The attached document, *Wind Summaries for Sitka, Ketchikan, Juneau, and Cordova (1987-1999)*, provides the data used to calculate the wind climatology in Glacier Bay proper. The document includes wind roses showing the speed and direction of wind events from 1987 through 1999.



Ketchikan (radial bands indicate 10 knot increments of wind speed
acting toward center of the wind rose)

Database: TDF14, TD3280 - Hourly Observations
Stations: Kethcikan Ap
Years: 1987-1999
Months: January-December
Days: 1-31
Hours: 12 am-11 pm

Note: Radial Bands indicate 10 knot increments of wind speed acting toward the center of the wind rose

Speed	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**	**Calm**
0-9 knots	1.27% (93)	0.04% (3)	0.05% (4)	0.10% (7)	1.65% (121)	6.06% (444)	13.10% (960)	13.56% (994)	8.87% (650)	1.10% (81)	0.46% (34)	0.10% (7)	0.38% (28)	2.70% (198)	5.25% (385)	3.67% (269)	18.09% (1326)
10-19 knots	0.11% (8)				0.10% (7)	3.04% (223)	10.93% (801)	5.85% (429)	0.74% (54)	0.01% (1)				0.11% (8)	0.75% (55)	0.91% (67)	
20-29 knots						0.14% (10)	0.74% (54)	0.14% (10)									
Unknown	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	

* Values in the table report the percentage and quantity for a given speed and direction.
* 'Calm' values are not graphed on the wind rose, but percentages and quantities are reported in the table.
* Unknown values are not included in percentages, only quantity is reported.

Please Read
Invalid Values are **NOT** included in the above calculations. The following information is presented to show the completeness of the database for your query. Please use this information to determine the validity and accuracy of the query results.

Your query returned 306 records.

A complete query should have returned at least 4748 records (1 for each hour (1945-83), 1 for each day (1984-99)).
7331 valid data cells were analyzed for your query.
A complete query should have analyzed 113952 data cells.
13 data cells were found to be invalid.
Possible reasons for an incomplete dataset are:

- One or more stations are not valid for the dates selected.
- Data is missing for a portion of the dates selected.

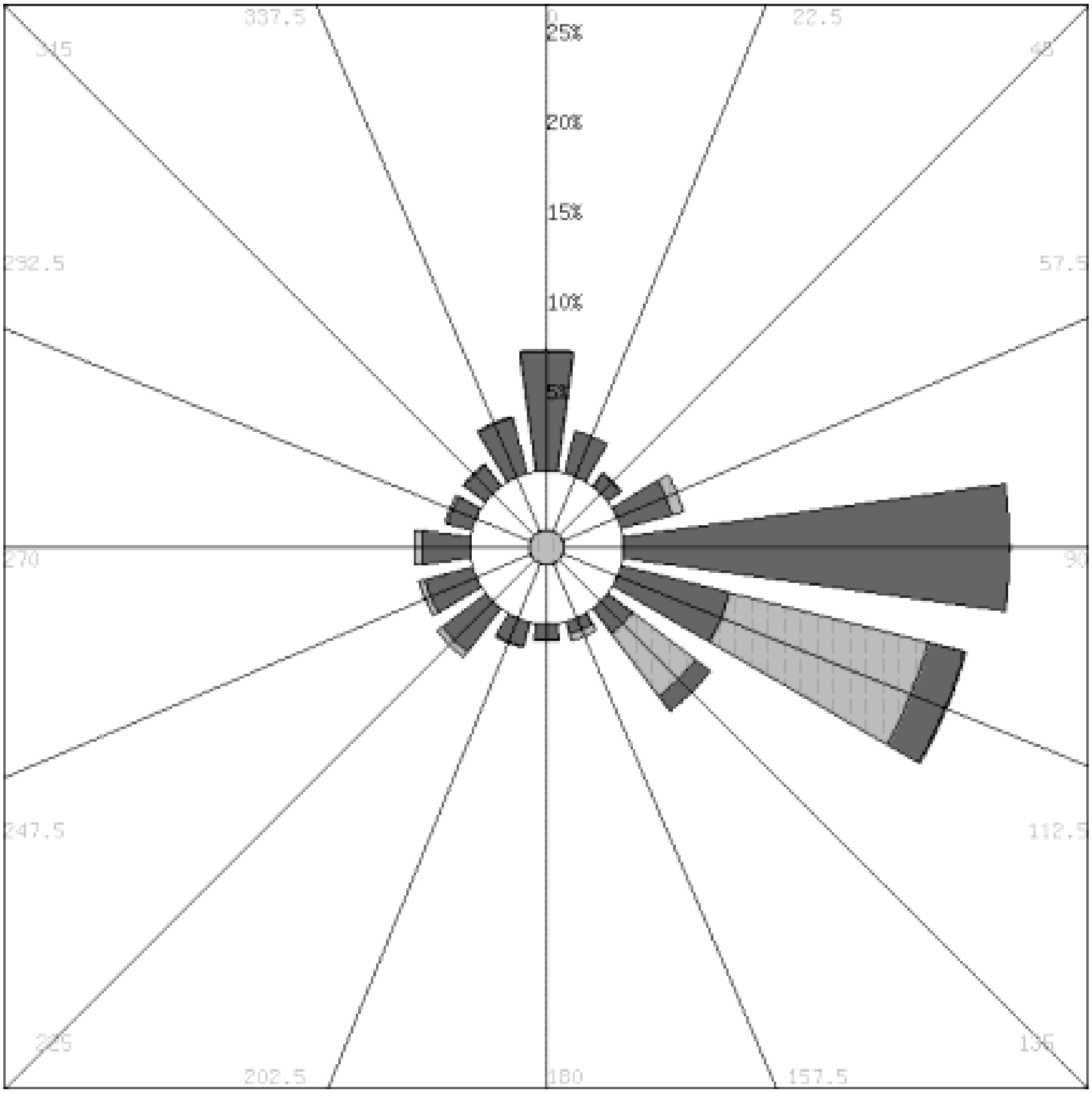
The dates found in the query are indicated below.

Station - KETHCIKAN AP (25325)												
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1999			1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31

The dates where invalid values were found are indicated below.

Station - KETHCIKAN AP (25325)												
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1999			1, 8-9, 29								28	

Change your search criteria by clicking here or by pressing the 'BACK' button on your browser.



Juneau (radial bands indicate 10 knot increments of wind speed acting
toward the center of the wind rose

Database: TDF14, TD3280 - Hourly Observations
Stations: Juneau Ap
Years: 1987-1999
Months: January-December
Days: 1-31
Hours: 12 am-11 pm

Note: Radial Bands indicate 10 knot increments of wind speed acting toward the center of the wind rose

Speed	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**	**Calm**	**Unknown**
0-9 knots	6.70% (7615)	2.44% (2779)	0.93% (1061)	2.94% (3349)	10.45% (11881)	6.22% (7073)	1.75% (1990)	0.71% (811)	0.89% (1017)	1.41% (1603)	3.09% (3509)	2.78% (3163)	2.73% (3100)	1.44% (1640)	1.54% (1753)	3.27% (3724)	21.52% (24474)	(3)
10-19 knots	0.08% (94)	0.04% (41)	0.08% (88)	0.71% (811)	6.74% (7666)	11.44% (13010)	4.40% (5006)	0.43% (487)	0.12% (136)	0.13% (152)	0.38% (434)	0.39% (441)	0.42% (476)	0.12% (136)	0.04% (46)	0.04% (49)		(0)
20-29 knots	0.00% (2)	0.00% (2)	0.00% (3)	0.01% (17)	0.28% (320)	2.07% (2352)	1.04% (1188)	0.05% (52)	0.01% (8)	0.00% (4)	0.00% (1)							(0)
30-39 knots					0.00% (1)	0.10% (112)	0.04% (50)											(0)
40-49 knots					0.00% (1)	0.00% (1)												(0)
Unknown	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)		(0)

* Values in the table report the percentage and quantity for a given speed and direction.
* 'Calm' values are not graphed on the wind rose, but percentages and quantities are reported in the table.
* Unknown values are not included in percentages, only quantity is reported.

Please Read
Invalid Values are **NOT** included in the above calculations. The following information is presented to show the completeness of the database for your query. Please use this information to determine the validity and accuracy of the query results.

Your query returned 4748 records.
A complete query should have returned at least 4748 records (1 for each hour (1945-83), 1 for each day (1984-99)).
113732 valid data cells were analyzed for your query.
A complete query should have analyzed 113952 data cells.
220 data cells were found to be invalid.
Possible reasons for an incomplete dataset are:

- One or more stations are not valid for the dates selected.
- Data is missing for a portion of the dates selected.

The dates found in the query are indicated below.

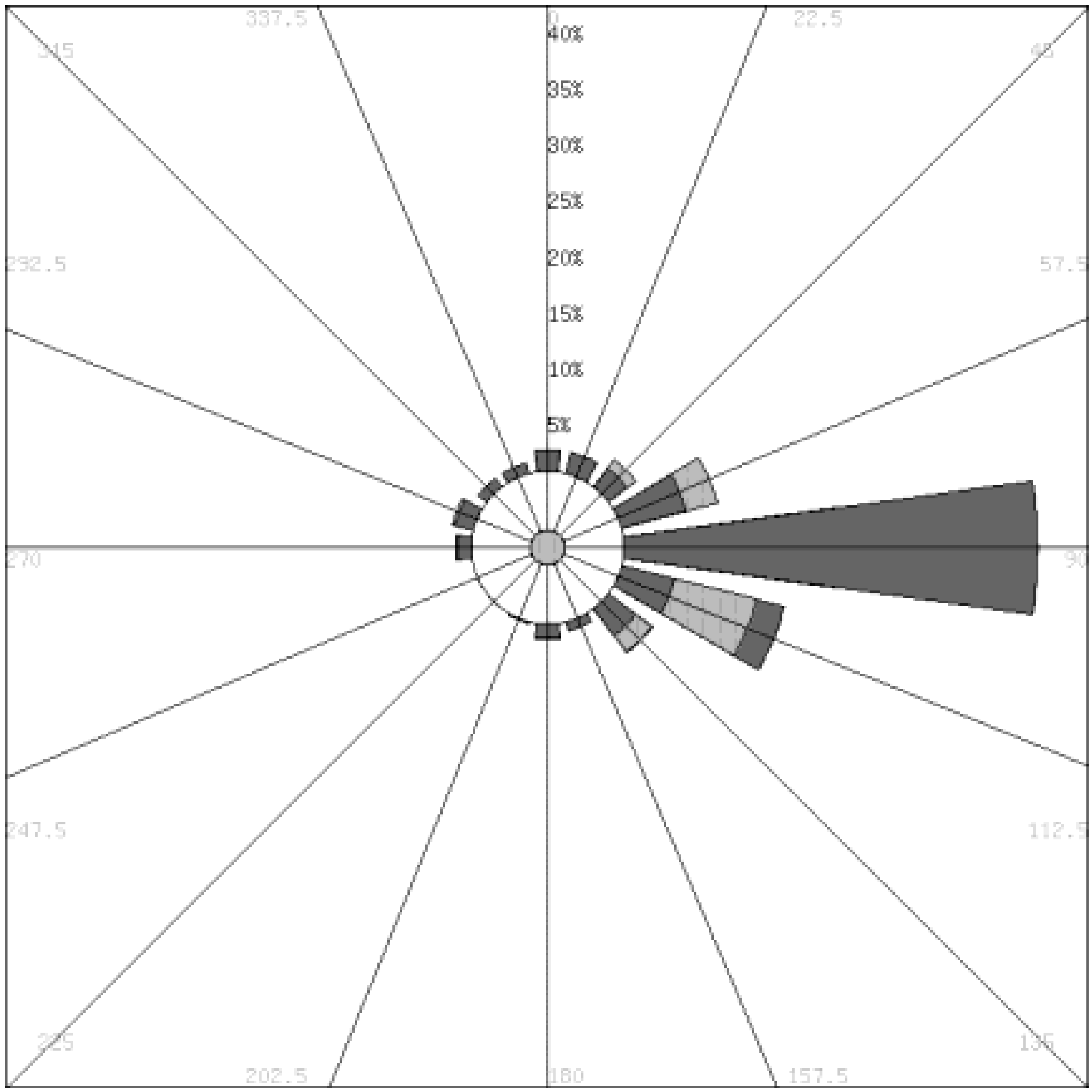
Station - JUNEAU AP (25309)												
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1987	1-31	1-28	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31
1988	1-31	1-29	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31
1989	1-31	1-28	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31
1990	1-31	1-28	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-18, 20-31
1991	1-31	1-28	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31
1992	1-31	1-29	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31
1993	1-31	1-28	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31
1994	1-31	1-28	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31
1995	1-31	1-28	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31
1996	1-31	1-29	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31
1997	1-31	1-28	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31
1998	1-31	1-28	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31

1999	1-31	1-28	1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31

The dates where invalid values were found are indicated below.

Station - JUNEAU AP (25309)												
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1987			1									
1988								19, 22-23	14			
1989											25-26, 29	6, 28
1990						28		2, 4-5, 7	18			12, 18, 20
1991			3					27				
1992									7			
1993					13-14	20					7, 15, 30	
1994		7			8				20-21, 24			
1995			6, 14, 18, 28, 30	3, 24			3, 9			2		20
1996	2, 11, 24, 29			2, 7, 9		15, 25	12, 20, 26	12, 18, 22-23, 27, 31	1, 13, 15, 17, 20, 25	2, 16-18, 31	1-2, 7, 19	1, 16
1997	16, 31	10, 21, 27	15	8, 14	4, 9	13, 26-27		6	6	11, 27		
1998	4, 29	2							18	5, 22		17
1999	3, 8, 10		28	18	3, 13							24-25

Change your search criteria by clicking here or by pressing the 'BACK' button on your browser.



Cordova (radial bands indicate 10 knot increments of wind speed acting
toward the center of the wind rose

Database: TDF14, TD3280 - Hourly Observations
Stations: Cordova Ap
Years: 1987-1999
Months: January-December
Days: 1-31
Hours: 12 am-11 pm

Note: Radial Bands indicate 10 knot increments of wind speed acting toward the center of the wind rose

Speed	**0°**	**22.5°**	**45°**	**67.5°**	**90°**	**112.5°**	**135°**	**157.5°**	**180°**	**202.5°**	**225°**	**247.5°**	**270°**	**292.5°**	**315°**	**337.5°**	**Calm**	**Unknown**
0-9 knots	2.03% (14)	2.03% (14)	2.17% (15)	5.93% (41)	10.71% (74)	4.92% (34)	3.04% (21)	0.87% (6)	1.30% (9)	0.14% (1)			1.30% (9)	1.74% (12)	1.01% (7)	1.01% (7)	36.90% (255)	(0)
10-19 knots			0.87% (6)	2.89% (20)	7.38% (51)	7.53% (52)	1.88% (13)		0.14% (1)				0.14% (1)	0.29% (2)				(0)
20-29 knots					1.16% (8)	2.46% (17)												(0)
30-39 knots							0.14% (1)											(0)
Unknown	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)		(0)

* Values in the table report the percentage and quantity for a given speed and direction.
* 'Calm' values are not graphed on the wind rose, but percentages and quantities are reported in the table.
* Unknown values are not included in percentages, only quantity is reported.

Please Read
Invalid Values are **NOT** included in the above calculations.

The following information is presented to show the completeness of the database for your query. Please use this information to determine the validity and accuracy of the query results.

Your query returned 30 records.
A complete query should have returned at least 4748 records (1 for each hour (1945-83), 1 for each day (1984-99)).
691 valid data cells were analyzed for your query.
A complete query should have analyzed 113952 data cells.
29 data cells were found to be invalid.
Possible reasons for an incomplete dataset are:

- One or more stations are not valid for the dates selected.
- Data is missing for a portion of the dates selected.

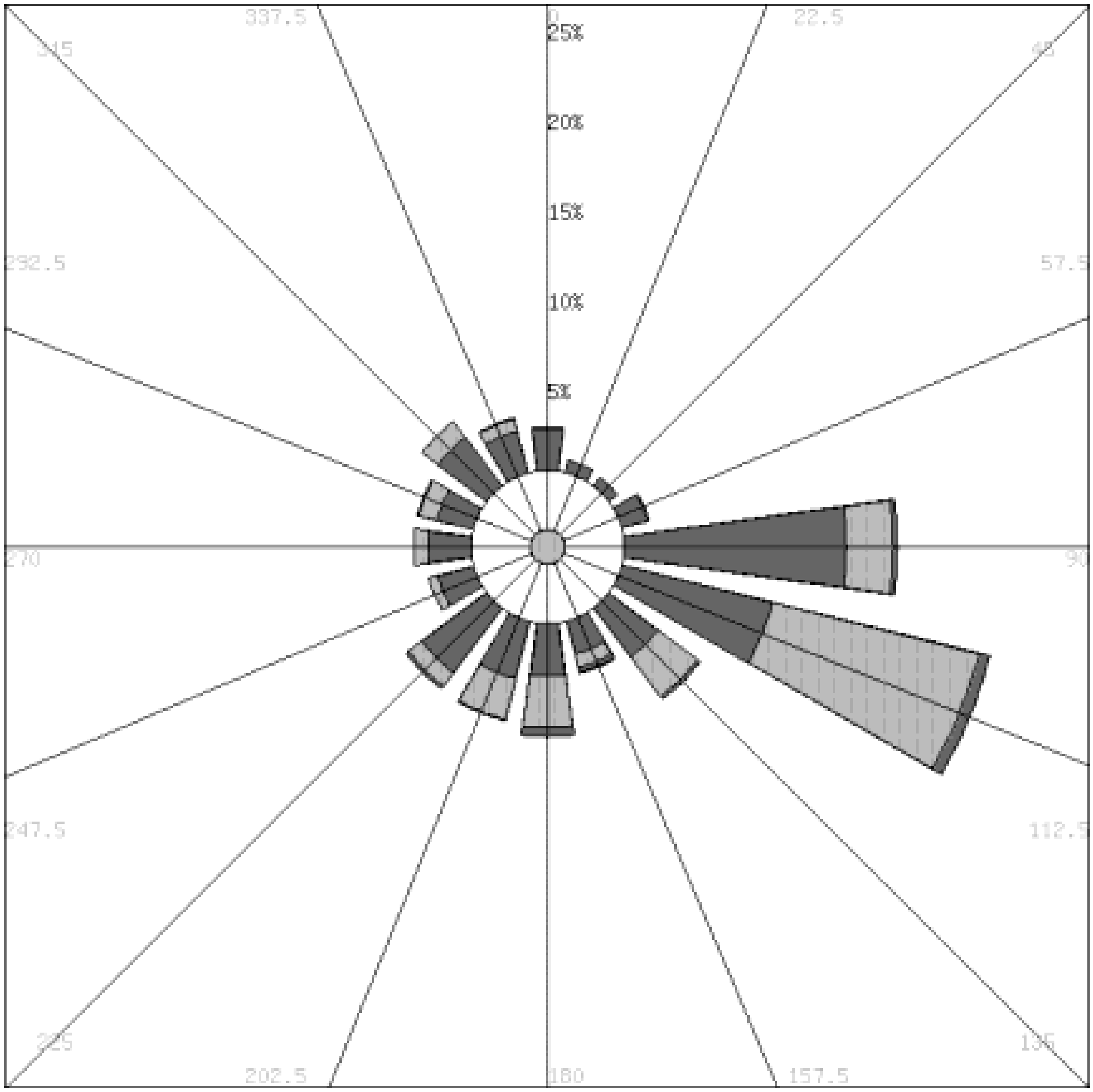
The dates found in the query are indicated below.

Station - CORDOVA AP (26410)												
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1999												1-30

The dates where invalid values were found are indicated below.

Station - CORDOVA AP (26410)												
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1999												1, 8, 13, 18, 30

Change your search criteria by clicking here or by pressing the 'BACK' button on your browser.



Sitka (radial bands indicate 10 knot increments of wind speed acting
toward the center of the wind rose

Database: TDF14, TD3280 - Hourly Observations
Stations: Sitka Ap
Years: 1987-1999
Months: January-December
Days: 1-31
Hours: 12 am-11 pm

Note: Radial Bands indicate 10 knot increments of wind speed acting toward the center of the wind rose

Speed	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Calm	Unknown
0-9 knots	2.35% (172)	0.70% (51)	0.61% (45)	1.54% (113)	12.38% (907)	8.69% (637)	3.49% (256)	1.92% (141)	2.95% (216)	3.30% (242)	4.50% (330)	2.10% (154)	2.48% (182)	2.09% (153)	3.37% (247)	2.43% (178)	14.32% (1049)	(0)
10-19 knots	0.10% (7)			0.04% (3)	2.61% (191)	11.79% (864)	2.76% (202)	0.82% (60)	2.89% (212)	2.36% (173)	1.01% (74)	0.53% (39)	0.74% (54)	1.09% (80)	1.15% (84)	0.75% (55)		(0)
20-29 knots					0.25% (18)	0.59% (43)	0.19% (14)	0.26% (19)	0.52% (38)	0.08% (6)	0.11% (8)		0.05% (4)	0.03% (2)		0.01% (1)		(0)
30-39 knots								0.03% (2)	0.01% (1)									(0)
Unknown	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)		(0)

* Values in the table report the percentage and quantity for a given speed and direction.
* 'Calm' values are not graphed on the wind rose, but percentages and quantities are reported in the table.
* Unknown values are not included in percentages, only quantity is reported.

Please Read
Invalid Values are **NOT** included in the above calculations.

The following information is presented to show the completeness of the database for your query.

Please use this information to determine the validity and accuracy of the query results.

Your query returned 306 records.
A complete query should have returned at least 4748 records (1 for each hour (1945-83), 1 for each day (1984-99)).
7327 valid data cells were analyzed for your query.
A complete query should have analyzed 113952 data cells.
17 data cells were found to be invalid.
Possible reasons for an incomplete dataset are:

- One or more stations are not valid for the dates selected.
- Data is missing for a portion of the dates selected.

The dates found in the query are indicated below.

Station - SITKA AP (25333)												
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1999			1-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-30	1-31

The dates where invalid values were found are indicated below.

Station - SITKA AP (25333)												
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1999			1, 3-5, 7, 30								23	

Change your search criteria by clicking here or by pressing the 'BACK' button on your browser.

Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants
1506 West 36th Avenue Anchorage, Alaska 99503 (907) 561-1011 Fax (907) 563-4220

Memorandum

To: File — Project No.: 02056.02

From: Jennifer Wilson — Date: October 3, 2002

Re: *Technical References*

Project: Glacier Bay National Park and Preserve Vessel Quotas and Operating Requirements Environmental Impact Statement, Appendix F Technical Memorandum

---

The attached document, *Technical References*, provides several technical documents used as the basis for the model at Glacier Bay proper. The theory behind these references was critical for deriving a model for identifying locations in Glacier Bay proper for site specific study and to conduct the study.

The technical references include:

Windspeed adjustment and wave growth, ACES Technical Reference
Coastal Engineering Manual III-1-8, II-1-74, and II-7-57 through -61
Chance of exceedance chart
Juneau extreme prediction chart

Windspeed Adjustment and Wave Growth

Description

The methodologies represented in this ACES application provide quick and simple estimates for wave growth over open-water and restricted fetches in deep and shallow water. Also, improved methods (over those given in the *Shore Protection Manual* (SPM), 1984) are included for adjusting the observed winds to those required by wave growth formulas.

Introduction

Wind-generated wave growth is a complex process of considerable practical interest. Although the process is only partially understood, substantial demand remains for quick estimates required for design and analysis procedures. The most accurate estimates available are those provided by sophisticated numerical models such as those presented in Cardone et al. (1976), Hasselmann et al. (1976), Resio (1981), and Resio (1987). Yet many studies, especially at the preliminary level, attempt to describe wind-generated wave growth without the benefit of intensive large-scale modeling efforts. The prediction methods that follow present a first-order estimate for the process, but their simplification of the more complex physics should always be considered.

Methods are included for adjusting observed winds of varying character and location to the conditions required by wave growth formulas. A model depicting an idealized atmospheric boundary layer over the water surface is employed to estimate the low-level winds above the water surface. Stability effects (air-sea temperature gradient) are included, but barotropic effects (horizontal temperature gradient) are ignored. The numerical descriptions of the planetary boundary layer model are based upon similitude theory. Additional corrections are provided for the observed bias of ship-based wind observations as well as short fetches. Formulas for estimating winds of alternate durations are also included. The methodology for this portion of the application is largely taken from Resio, Vincent, and Corson (1982).

The simplified wave growth formulas predict deepwater wave growth according to fetch- and duration-limited criteria and are bounded (at the upper limit) by the estimates for a fully developed spectrum. The shallow-water formulations are based partly upon the fetch-limited deepwater forms and do not encompass duration effects. The methods described are essentially those in Vincent (1984), the SPM (1984), and Smith (1991).

Unless otherwise annotated, metric units are assumed for the following discussion.

General Assumptions and Limitations

The deep- and shallow-water wave growth curves are based on limited field data that have been generalized and extended on the basis of dimensionless analysis. The wind estimation procedures are based on a combination of boundary layer theory and limited field data largely from the Great Lakes. Wind transformation from land to water tends to be highly site and condition specific. The derivation of an individual site from these generalized conditions can create significant errors. Collection of site-specific field data to calibrate the techniques is suggested.

WIND ADJUSTMENT

The methodology for preparing wind observations for use in the wave growth formulas is based upon an idealized model of the planetary boundary layer depicted in Figure 1-1-1. For typical mid-latitude conditions, this planetary boundary layer exists in the lowest kilometer of the atmosphere and contains about 10 percent of the atmospheric mass (Holton, 1979).

Low-level winds directly over the water surface are considered to exist in a region characterized as having relatively constant stress at the air-sea interface. This surface layer will be designated the constant stress region for the remainder of this discussion.

Above the constant stress region is the Ekman layer, where the additional forces of Coriolis force, pressure gradient force, viscous stress, and convectively driven mixing are considered important.

Finally, above the Ekman region, geostrophic winds are considered to exist which result from considering the balance between pressure gradient forces and Coriolis force for synoptic scale systems.

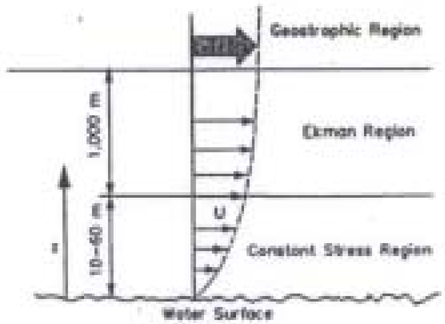


Figure 1-1-1. Idealized Atmospheric Boundary Layer over Water

Observed winds for use in the wave growth equations are considered to be characterized by six categories summarized in Table 1-1-1.

Table 1-1-1
Character and Action for Wind Observations

Observation type	Initial Action	Solution Domain
Over water (non-ship obs)	-------	Constant stress layer
Over water (ship obs)	Adjusted	Constant stress layer
At shoreline (onshore winds)	-------	Constant stress layer
At shoreline (offshore winds)	Geostrophic wind estimated	Full PBL* model
Over land	Geostrophic wind estimated	Full PBL model
Geostrophic wind	-------	Full PBL model

* PBL = Planetary Boundary Layer

Although the above six wind observation categories are presented for user convenience, only two separate cases are ultimately considered by the methodology: low-level winds observed within the constant stress region and known or estimated geostrophic winds. In the ACES application, adjustments for ship-based observations are made before proceeding with a solution in the constant stress region, and geostrophic winds are estimated for cases where low-level observed winds are predominantly over land masses. The case of observed winds blowing onshore and measured at the shoreline is considered to be effectively identical to the case of winds observed over water. Similarly, winds observed at the shoreline but blowing from the land mass in an offshore direction are considered effectively equivalent to winds observed at a more inland location. Complex wind patterns caused by local frictional characteristics or topography are obviously not considered by these simplifications.

Initial Adjustments and Estimates

Wind observations over water are typically the most desirable choice of available data sources for wave prediction. Observers on ships at sea frequently record such data and make qualitative estimates. Cardone (1969) reviewed the bias of ship-based observations and suggested the following adjustment:

$$U = 1.864\, U_{obs}^{\frac{7}{9}} \qquad (mps) \tag{1}$$

where

U = adjusted ship-based wind speed

U_{obs} = ship-based observations

For cases where the observed winds are predominantly over land surfaces, similar models of the boundary layer are sometimes employed for other prediction purposes. However, in this application, the following simple estimate for geostrophic winds is made from low-level wind observations (cgs units):

$$V_g = \frac{U_*}{\sqrt{C_{D_{land}}}} \tag{2}$$

where

U_* = friction velocity

$$= \frac{k U_{obs}}{\ln\left(\frac{z_{obs}}{z_0}\right)} \tag{3}$$

k = von Karman constant ($k = 0.4$)

z_{obs} = elevation of wind observation

z_0 = surface roughness length (assumed = 30 cm)

$C_{D_{land}}$ = drag coefficient over land

$$C_{D_{land}} = 0.00255\, z_0^{0.1639} \tag{4}$$

Constant Stress Region

The major features of the constant stress region can be summarized as follows:

- The constant stress region is confined to the lowest few meters of the boundary layer.
- Wind flow is assumed parallel to the water surface.
- The wind velocity is adjusted so that the horizontal frictional stress is nearly independent of height.
- The stress remains constant within the layer and is characterized by the friction velocity U_* .

Stability (air-sea temperature gradient) has an important effect on wave growth. The wind profile within this region is described by the following modified logarithmic form:

$$U_z = \frac{U_*}{k}\left[\ln\left(\frac{z}{z_0}\right) - \Psi\left(\frac{z}{L'}\right)\right] \tag{5}$$

where

U_z = wind velocity at elevation z

z_0 = surface roughness length

$$= \frac{C_1}{U_*} + C_2 U_*^2 + C_3 \tag{6}$$

$$\left(C_1 = 0.1525 \ , \ C_2 = \frac{0.019}{980} \ , \ C_3 = -0.00371\right) \tag{7}$$

Ψ = universal similarity function
KEYPS formula (Lumley and Panofsky, 1964)

L' = Obukov stability length

$$= 1.79\frac{U_*^2}{\Delta T}\left[\ln\left(\frac{z}{z_0}\right) - \Psi\left(\frac{z}{L'}\right)\right] \tag{8}$$

ΔT = air-sea temperature gradient

$$\left.\begin{aligned} &\Psi = 0 && \mid \Delta T = 0 \\ &\Psi = C\frac{z}{L'} && \mid \frac{z}{L'} > 0 \\ &\Psi = 1 - \phi_u - 3\ln\phi_u + 2\ln\left(\frac{1+\phi_u}{2}\right) + 2\tan^{-1}\phi_u - \frac{\pi}{2} + \ln\left(\frac{1+\phi_u^2}{2}\right) && \mid \frac{z}{L'} \le 0 \end{aligned}\right\} \tag{9}$$

$$\phi_u = \frac{1}{1 - 18R_i^{1/4}} \tag{10}$$

$$R_i = \frac{z}{L'}(1 - 18R_i)^{1/4} \tag{11}$$

The solution of the above equations is an iterative process that converges very rapidly. The convergence criterion (ϵ) for U_* and L' are given below:

$$\epsilon_{U_*} \rightarrow 0.1\,(cm/sec) \qquad \text{and} \qquad \epsilon_{L'} \rightarrow 1\,(cm) \tag{12}$$

The wave growth equations discussed later require the equivalent wind speed at a 10-m elevation under conditions of neutral stability ($\Delta T = 0$). Having solved the equations in the constant stress region for U_*, the required equivalent neutral wind speed U_e may be easily obtained from Equation 5 using (U_*, $z = 10\,m$, $\Delta T = 0$):

$$U_{e_{1000}} = \frac{U_*}{k}\left[\ln\left(\frac{1000}{z_0}\right) - 0\right] \tag{13}$$

Full Boundary Layer

For cases where the geostrophic winds are known or have been estimated, the similitude equations describing the entire planetary boundary layer are solved. In addition to the relations described above for the constant stress region, the following relationships describe the model from water surface level to the geostrophic level:

$$\ln\frac{|\overline{V}_g|}{f z_0} = A - \ln\frac{U_*}{|\overline{V}_g|} + \sqrt{\frac{k^2|\overline{V}_g|^2}{U_*^2} - B^2} \tag{14}$$

$$\sin\theta = \frac{BU_*}{k|\overline{V}_g|} \tag{15}$$

where

$\overline{V}_g$ = geostrophic wind

f = Coriolis acceleration

A, B = nondimensional functions of stability

$$\left.\begin{aligned} A &= A_0[1 - e^{(0.015\mu)}] \\ B &= B_0 - B_1[1 - e^{(0.03\mu)}] \end{aligned}\right| \quad \mu \leq 0 \tag{16}$$

$$\left.\begin{aligned} A &= A_0 - 0.96\sqrt{\mu} + \ln(\mu + 1) \\ B &= B_0 + 0.7\sqrt{\mu} \end{aligned}\right| \quad \mu > 0 \tag{17}$$

μ = dimensionless stability parameter

$$= \frac{kU_*}{fL'} \tag{18}$$

A_0, B_0, B_1 = constants

θ = angle between $\overline{V}_g$ and the surface stress

Equations *14-18* are solved simultaneously together with Equations *5-11* until the convergence of U_*, L', and A is obtained. A slightly different value of $(C_2 = 0.0144/980)$ in Equation *7* is used (Dr. C. Linwood Vincent, CERC, personal communication, September 1989). The convergence criteria for the iterative solution to the equations are as follows:

$$\epsilon_{U_*} \rightarrow 0.1(cm/\sec) \quad \text{and} \quad \epsilon_{L'} \rightarrow 1(cm) \quad \text{and} \quad \epsilon_A \rightarrow 0.1 \tag{19}$$

The solution procedure converges very rapidly. As before, Equation *13* is then used to determine the equivalent neutral wind speed at the 10-m elevation using $(U_*,\ z=10\ m,\ \Delta t=0)$.

Final Adjustments

An additional adjustment is made for situations having relatively short fetch lengths before application of the wave growth equations. For fetch lengths shorter than 16 km, the following reduction is applied:

$$U_a = 0.9U_a \tag{20}$$

Finally, it is necessary to evaluate the effects of winds of varying duration, t_t, on the wave growth equations. The following expressions are used to adjust the wind speed to a duration of interest:

$$\frac{U_t}{U_{3600}} = 1.277 + 0.296\tanh\left(0.9\log\frac{45}{t_t}\right) \quad \Big| \quad (1 < t_t < 3600\,\sec) \tag{21}$$

$$\frac{U_t}{U_{3600}} = -0.15\log t_t + 1.5334 \quad \Big| \quad (3600 < t_t < 36000\,\sec) \tag{22}$$

The 1-hr wind speed U_{3600} is first determined (using $t_t = t_{obs}$). The wind speed U_t at the desired duration of interest is then determined by selecting the desired t_t and using the appropriate equation.

Wave Growth

Having estimated the winds above the water surface at a duration of interest, the objective is to provide an estimate of the wave growth caused by the winds. The simple wave growth formulas that follow provide quick estimates for wind-wave growth in deep and shallow water. The open-water expressions correspond to those listed in the SPM (1984) and Vincent (1984). The restricted fetch deepwater expressions can be found in Smith (1991). It should be noted that the drag law (Garratt, 1977) employed differs from that in the SPM. The major assumptions regarding the use of the simplified wave growth expressions include:

- Energy from the presence of other existing wave trains is neglected.
- Relatively short fetch geometries ($F \leq 75\,\mathrm{mi}$).
- Relatively constant wind speed ($\Delta U \leq 5\,\mathrm{kts}$) and direction ($\Delta\alpha \leq 15°$).
- Winds prescribed at the *10-m* elevation ($z = 10\,\mathrm{m}$).
- Neutral stability conditions.
- Fixed value of drag coefficient ($C_D = 0.001$).

The wind adjustment methodology described earlier in this report adjusts the observed wind, U_{obs}, to the 10-m elevation under neutrally stable conditions U_*. Vincent (1984) maintains the wind speed should be adjusted to consider the nonlinear effect on the wind stress creating the waves. The drag law reported by Garratt (1977) is used:

$$\tau = \rho_a C_D U^2 \tag{23}$$

where

ρ = air density

$$C_D = 0.001\,(0.75 + 0.067\,U) \tag{24}$$

The equivalent neutral wind speed, then, is adjusted (or linearized) to a constant drag coefficient ($C_D = 0.001$) before application in the wave growth formulas:

$$U_a = U_* \sqrt{\frac{C_D}{0.001}} \tag{25}$$

Fetch Considerations

The wave growth formulations which follow are segregated into four categories: deep and shallow-water forms for both simple open-water fetches and for more complex, limiting geometries (designated "restricted fetch"). A brief discussion of fetch delineation is useful.

Open-Water Fetches

In open water, wave generation is limited by the dimensions of the subject meteorological event, and fetch widths are of the same order of magnitude as the fetch length. The simplified estimates for wave growth in open water attribute significance to the fetch length (but not width or shape). The wave growth is assumed to occur along the fetch in the direction of the wind.

Restricted Fetches

The more limiting or complex geometries of water bodies such as lakes, rivers, bays, and reservoirs have an impact on wind-wave generation. This restricted fetch methodology applies the concept of wave development in off-wind directions and considers the shape of the basin. The details of the method are reported by Smith (1991), and are based upon a concept reported by Donelan (1980) whereby the wave period (as a function of fetch lengths at off-wind directions) is maximized. For this approach, the radial fetch lengths (as measured from various points along the shoreline of the basin to the point of interest) are used to describe the geometry of the basin. In addition, the wind direction must be specified. Figure 1-1-2 illustrates the relevant geometric data required for the restricted fetch approach.

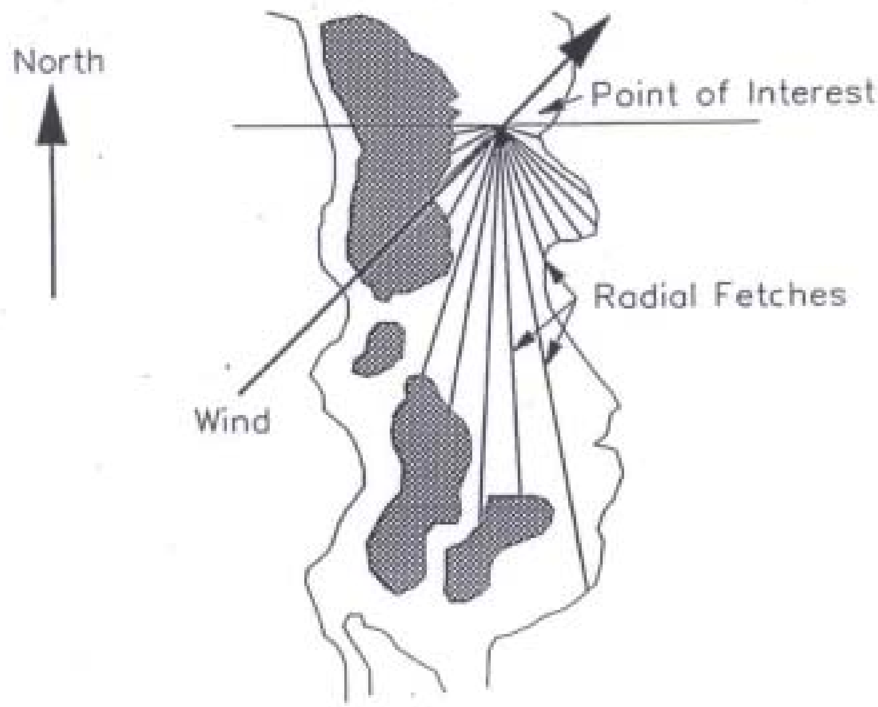


Figure 1-1-2. Restricted Fetch Geometry Data

The conventions used for specifying wind direction and fetch geometry are illustrated in Figure 1-1-3. The approach wind direction (α) as well as the radial fetch angles (β_i), and ($\Delta\beta$) should be specified in a clockwise direction from north from the point of interest where wave growth prediction is required.

From the specified radial fetch data, intermediate values are interpolated at 1-deg increments around the entire 360-deg compass. These interpolated fetches are subsequently averaged over 15-deg arcs centered at each whole 1-deg value.

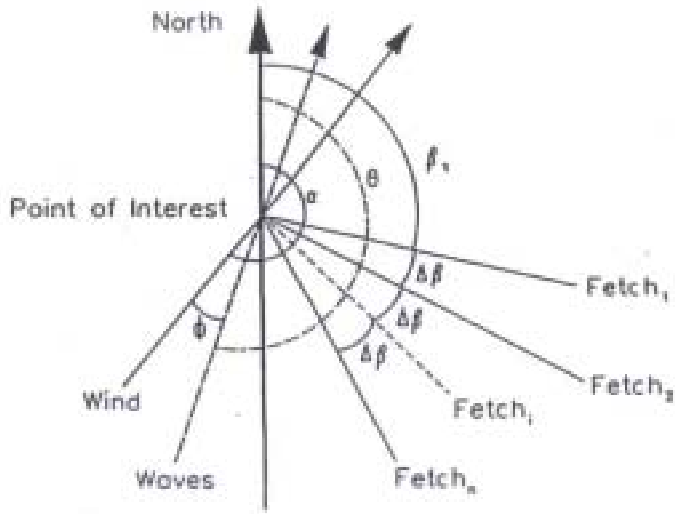


Figure 1-1-3. Restricted Fetch Conventions

The direction of wave development (θ) is solved by maximizing the product

$$F_{*}^{0.28} \cdot (\cos\phi)^{0.44} \tag{26}$$

This procedure maximizes the relevant terms in the expression for wave period (T_p) (Equation *36*). The angle (ϕ) is defined as the off-wind direction angle associated with the interpolated averaged fetch length value (F_*). Product results (Equation *26*) are evaluated from ($\phi = 0 \pm 90°$) at 1-deg increments. When the product (Equation *26*) is maximized, (ϕ) represents the angle between the wind and waves, and (θ) represents the compass direction from which wave development occurs along (F_*). For a specified wind direction, there will be a corresponding wave development direction where (T_p) is maximized by Equation *26*.

Deepwater Wave Growth

The formulas for wave growth in deep water encompass the effects of fetch and duration. The open-water formulas for fetch- and duration-limited wave growth are taken from Vincent (1984) and are based upon the spectrally based results given in Hasselmann et al. (1973, 1976). The fetch-limited and fully developed forms are also tabulated in the SPM (1984). The expressions for restricted fetch wave growth in deep water are from Smith (1991). In all cases, the wave growth estimates are bounded by the expressions for a fully developed equilibrium spectrum. The procedure is outlined as follows:

- Determine the minimum duration, t_{fetch}, required for a wave field to become fetch-limited:

Open Water

$$t_{fetch} = 68.8 \frac{F^{2/3}}{g^{1/3} U_a^{1/3}} \tag{27}$$

Restricted Fetch

$$t_{fetch} = 51.09 \frac{F^{0.72}}{g^{0.28} \bar{U}_a^{0.44}} \tag{28}$$

- Determine the character of the wave growth (duration-limited or fetch-limited):

Open Water		Restricted Fetch
$H = 0.0000851 \left(\frac{U_a^2}{g}\right)\left(\frac{g t_l}{U_a}\right)^{5/7}$ (29)	Duration Limited	$H = 0.000103 \left(\frac{\bar{U}_a^2}{g}\right)\left(\frac{g t_l}{\bar{U}_a}\right)^{0.69}$ (30)
$T = 0.0702 \left(\frac{U_a}{g}\right)\left(\frac{g t_l}{U_a}\right)^{0.411}$ (31)	$(t_l < t_{fetch})$	$T = 0.082 \left(\frac{\bar{U}_a}{g}\right)\left(\frac{g t_l}{\bar{U}_a}\right)^{0.39}$ (32)

--- or ---

$H = 0.0016 \left(\frac{U_a^2}{g}\right)\left(\frac{gF}{U_a^2}\right)^{1/2}$ (33)	Fetch Limited	$H = 0.0015 \left(\frac{\bar{U}_a^2}{g}\right)\left(\frac{gF}{\bar{U}_a^2}\right)^{1/2}$ (34)
$T = 0.2857 \left(\frac{U_a}{g}\right)\left(\frac{gF}{U_a^2}\right)^{1/3}$ (35)	$(t_l \geq t_{fetch})$	$T = 0.3704 \left(\frac{\bar{U}_a}{g}\right)\left(\frac{gF}{\bar{U}_a^2}\right)^{0.28}$ (36)

- Determine the "fully developed" condition:

Open Water		Restricted Fetch
$H_{fd} = 0.2433 \left(\frac{U_a^2}{g}\right)$ (37)	Fully Developed	$H_{fd} = 0.2433 \left(\frac{\bar{U}_a^2}{g}\right)$ (38)
$T_{fd} = 8.134 \left(\frac{U_a}{g}\right)$ (39)		$T_{fd} = 8.134 \left(\frac{\bar{U}_a}{g}\right)$ (40)

- Ensure that the "fully developed" condition is not exceeded:

$$H_{m0} = \min(H, H_{fd}) \tag{41}$$

$$T_p = \min(T, T_{fd}) \tag{42}$$

where

g = acceleration due to gravity

t_t = wind duration used in duration-limited expressions

F = fetch length used in fetch-limited expressions

$\bar{U}_a = U_a \cos(\phi)$ = fetch-parallel component of U_a for restricted fetch approach

$\bar{U}_* = U_* \cos(\phi)$ = fetch-parallel component of U_* for restricted fetch approach

H = wave height determined by duration-limited or fetch-limited expressions

T = wave period determined by duration-limited or fetch-limited expressions

H_{fd} = wave height limited by fully developed spectrum criteria

T_{fd} = wave period limited by fully developed spectrum criteria

H_{m0} = final wave height determined from spectrally based methods

T_p = final wave period determined from spectrally based methods

Shallow-Water Wave Growth

Estimates for wave growth in shallow water are based upon the fetch-limited deepwater formulas, but modified to include the effects of bottom friction and percolation (Bretschneider and Reid, 1954). Water depth is assumed to be constant over the fetch. Duration-limited effects are not embodied by these formulas. The relationships have not been verified and may (or may not) be appropriate for the conditions and assumptions of the original Bretschneider-Reid work. **The expressions represent an interim method pending results of further research.** The open-water forms are also presented in the SPM (1984).

Open-Water Forms:

$$H_{m0} = \frac{U_a^2}{g} 0.283 \tanh\left[0.530\left(\frac{gd}{U_a^2}\right)^{0.75}\right] \tanh\left\{\frac{\frac{0.0016}{0.283}\left(\frac{gF}{U_a^2}\right)^{0.5}}{\tanh\left[0.530\left(\frac{gd}{U_a^2}\right)^{0.75}\right]}\right\} \qquad (43)$$

$$T_p = \frac{U_a}{g} 7.54 \tanh\left[0.833\left(\frac{gd}{\bar{U}_a^2}\right)^{0.375}\right] \tanh\left\{\frac{\frac{0.2857}{7.54}\left(\frac{gF}{\bar{U}_a^2}\right)^{0.333}}{\tanh\left[0.833\left(\frac{gd}{\bar{U}_a^2}\right)^{0.375}\right]}\right\} \qquad (44)$$

Restricted Fetch Forms:

$$H_{m0} = \frac{U_a^2}{g} 0.283 \tanh\left[0.530\left(\frac{gd}{U_a^2}\right)^{0.75}\right] \tanh\left\{\frac{\frac{0.0015}{0.283}\left(\frac{gF}{U_a^2}\right)^{0.5}}{\tanh\left[0.530\left(\frac{gd}{U_a^2}\right)^{0.75}\right]}\right\} \quad (45)$$

$$T_p = \frac{U_a}{g} 7.54 \tanh\left[0.833\left(\frac{gd}{U_a^2}\right)^{0.375}\right] \tanh\left\{\frac{\frac{0.3704}{7.54}\left(\frac{gF}{U_a^2}\right)^{0.28}}{\tanh\left[0.833\left(\frac{gd}{U_a^2}\right)^{0.375}\right]}\right\} \quad (46)$$

References and Bibliography

Bretschneider, C. L., and Reid, R. O. 1954. "Modification of Wave Height Due to Bottom Friction, Perlocation and Refraction," Technical Report 50-1, The Agricultural and Mechanical College of Texas, College Station, TX.

Cardone, V. J. 1969. "Specification of the Wind Distribution in the Marine Boundary Layer for Wave Forecasting," TR-69-1, Geophysical Sciences Laboratory, Department of Meteorology and Oceanography, School of Engineering and Science, New York University, New York.

Cardone, V. J., et al. 1976 "Hindcasting the Directional Spectra of Hurricane-Generated Waves," *Journal of Petroleum Technology*, American Institute of Mining and Metallurgical Engineers, No. 261, pp. 385-394.

Donelan, M.A. 1980. "Similarity Theory Applied to the Forecasting of Wave Heights, Periods, and Directions," *Proceedings of the Canadian Coastal Conference*, National Research Council, Canada, pp. 46-61.

Garratt, J. R., Jr. 1977. "Review of Drag Coefficients over Oceans and Continents," *Monthly Weather Review*, Vol. 105, pp. 915-929.

Hasselmann, K., Barnett, T. P., Bonws, E., Carlson H., Cartwright, D. C., Enke, K., Ewing, J., Gienapp, H., Hasselmann, D. E., Kruseman, P., Meerburg, A., Muller, P., Olbers, D. J., Richter, K., Sell, W., and Walden, H. 1973. "Measurements of Wind-Wave Growth and Swell Decay During the Joint North Sea Wave Project (JONSWAP)," Deutches Hydrographisches Institut, Hamburg, 95 pp.

Hasselmann, K., Ross, D. B., Muller, P., and Sell, W. 1976. "A Parametric Prediction Model," *Journal of Physical Oceanography*, Vol. 6, pp. 200-228.

Holton, J. R. 1979. *An Introduction to Dynamic Meteorology*, Academic Press, Inc., New York, pp. 102-118.

Lumley, J. L., and Panofsky, H. A. 1964. *The Structure of Atmospheric Turbulence*, Wiley, New York.

Mitsuyasu, H. 1968. "On the Growth of the Spectrum of Wind-Generated Waves (I)," Reports of the Research Institute of Applied Mechanics, Kyushu University, Fukuoka, Japan, Vol. 16, No. 55, pp. 459-482.

Resio, D. T. 1981. "The Estimation of Wind Wave Generation in a Discrete Model," *Journal of Physical Oceanography*, Vol. 11, pp. 510-525.

Resio, D. T. 1987. "Shallow Water Waves. I: Theory," *Journal of Waterway, Port, Coastal and Ocean Engineering*, American Society of Civil Engineers, Vol. 113, No. 3, pp. 264-281.

Resio, D. T., Vincent, C. L., and Corson, W. D. 1982. "Objective Specification of Atlantic Ocean Wind Fields from Historical Data," Wave Information Study Report No. 4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Shore Protection Manual. 1984. 4th ed., 2 Vols., US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, US Government Printing Office, Washington, DC, Chapter 3, pp. 24-66.

Smith, J.M. 1991. Wind-Wave Generation on Restricted Fetches," Miscellaneous Paper CERC-91-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Vincent, C. L. 1984. "Deepwater Wind Wave Growth with Fetch and Duration," Miscellaneous Paper CERC-84-13, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table III-1-2
Sediment Particle Sizes

ASTM (Unified) Classification[1]	U.S. Std. Sieve[2]	Size in mm	Phi Size	Wentworth Classification[3]
Boulder		4096.	-12.0	
		1024.	-10.0	Boulder
	12 in. (300 mm)	256.	-8.0	Large Cobble
		128.	-7.0	
Cobble		107.64	-6.75	
		90.51	-6.5	Small Cobble
	3 in. (75 mm)	76.11	-6.25	
		64.00	-6.0	
		53.82	-5.75	
		45.26	-5.5	Very Large Pebble
Coarse Gravel		38.05	-5.25	
		32.00	-5.0	
		26.91	-4.75	
		22.63	-4.5	Large Pebble
	3/4 in. (19 mm)	19.03	-4.25	
		16.00	-4.0	
		13.45	-3.75	
		11.31	-3.5	Medium Pebble
		9.51	-3.25	
Fine Gravel	2.5	8.00	-3.0	
	3	6.73	-2.75	
	3.5	5.66	-2.5	Small Pebble
	4 (4.75 mm)	4.76	-2.25	
	5	4.00	-2.0	
	6	3.36	-1.75	
Coarse Sand	7	2.83	-1.5	Granule
	8	2.38	-1.25	
	10 (2.0 mm)	2.00	-1.0	
	12	1.68	-0.75	
	14	1.41	-0.5	Very Coarse Sand
	16	1.19	-0.25	
	18	1.00	0.0	
Medium Sand	20	0.84	0.25	
	25	0.71	0.5	Coarse Sand
	30	0.59	0.75	
	35	0.50	1.0	
	40 (0.425 mm)	0.420	1.25	
	45	0.354	1.5	Medium Sand
	50	0.297	1.75	
	60	0.250	2.0	
	70	0.210	2.25	
Fine Sand	80	0.177	2.5	Fine Sand
	100	0.149	2.75	
	120	0.125	3.0	
	140	0.105	3.25	
	170	0.088	3.5	Very Fine Sand
	200 (0.075 mm)	0.074	3.75	
Fine-grained Soil:	230	0.0625	4.0	
	270	0.0526	4.25	
Clay if PI ≥ 4 and plot of PI vs. LL is on or above "A" line and the presence of organic matter does not influence LL.	325	0.0442	4.5	Coarse Silt
	400	0.0372	4.75	
		0.0312	5.0	Medium Silt
		0.0156	6.0	Fine Silt
		0.0078	7.0	Very Fine Silt
Silt if PI < 4 and plot of PI vs. LL is below "A" line and the presence of organic matter does not influence LL.		0.0039	8.0	Coarse Clay
		0.00195	9.0	Medium Clay
		0.00098	10.0	Fine Clay
		0.00049	11.0	
(PI = plasticity limit; LL = liquid limit)		0.00024	12.0	
		0.00012	13.0	
		0.000061	14.0	

[1] ASTM Standard D 2487-92. This is the ASTM version of the Unified Soil Classification System. Both systems are similar (from ASTM (1994)).
[2] Note that British Standard, French, and German DIN mesh sizes and classifications are different.
[3] Wentworth sizes (in inches) cited in Krumbein and Sloss (1963).

(7) Wave height distribution.

(a) The heights of individual waves may be regarded as a stochastic variable represented by a probability distribution function. From an observed wave record, such a function can be obtained from a histogram of wave heights normalized with the mean heights in several wave records measured at a point (Figure II-1-30). Thompson (1977) indicated how well coastal wave records follow the Rayleigh distribution. If wave energy is concentrated in a very narrow range of wave period, the maxima of the wave profile will coincide with the wave crests and the minima with the troughs. This is termed a *narrow-band condition*. Under the narrow-band condition, wave heights are represented by the following Rayleigh distribution (Longuet-Higgins 1952, 1975b, 1983)

$$p(H) = \frac{2H}{H_{rms}^2} \exp\left[-\frac{H^2}{H_{rms}^2}\right]$$

$$P(H) = 1 - \exp\left[-\frac{H^2}{H_{rms}^2}\right] \qquad \text{(II-1-130)}$$

(b) The significant wave height $H_{1/3}$ is the centroid of the area for $H > H_*$ under the density function where $H > H_*$ corresponds to waves in the highest one-third range as shown in Figure II-1-29, that is

$$P(H_*) = 1 - \frac{1}{3} = 1 - e^{\left(-\frac{H_*^2}{H_{rms}^2}\right)} \qquad \text{(II-1-131)}$$

from which we find $H_* = 1.05H_{rms}$. Various estimates of wave heights may then be obtained upon integration of the above equation using certain mathematical properties of the Error function (Abramowitz and Stegun 1965). We find

$$\begin{aligned} H_{1/3} &= 4.00\sqrt{m_0} = 1.416\,H_{rms} \\ H_{1/10} &= 1.27\,H_{1/3} = 1.800\,H_{rms} = 5.091\sqrt{m_0} \\ H_{1/100} &= 1.67\,H_{1/3} = 2.36\,H_{rms} = 6.672\sqrt{m_0} \\ H_{max} &= 1.86\,H_{1/3} \quad \textit{(for 1000 wave cycles in the record)} \end{aligned} \qquad \text{(II-1-132)}$$

(c) The *most probable maximum wave height* in a record containing N waves is related to the rms wave height (Longuet-Higgins 1952) by

$$H_{max} = \left[\sqrt{\log N} + \frac{0.2886}{\sqrt{\log N}} - \frac{0.247}{(\log N)^{3/2}}\right] H_{rms} \qquad \text{(II-1-133)}$$

To: [illegible]
From: Orson Smith 7/18/02

remedial efforts that may be necessary. Or the model may then be run to evaluate proposed modifications of the harbor.

An alternative is to run more extensive field studies as the sole effort to evaluate conditions at a harbor. This would generally be more costly than the hybrid field-model approach, but it may provide some detail that can not be achieved from model studies alone.

Also, field studies have been done to support the general development of physical and numerical modelling techniques for the study of harbor flushing and circulation.

Field measurements include those that define the hydrodynamics of a harbor and supplementary measurements to quantify harbor flushing. The former include measurements of tide levels inside and outside of the harbor, current velocity measurements at the entrance to quantify flow rates into and out of the harbor, and flow velocity measurements throughout the harbor and/or drogue studies to define circulation patterns in the harbor. If tidal flushing is the primary concern, these measurements would be conducted on days when the wind velocity is low. Otherwise, a directional anemometer would also be used to measure the wind speed and direction.

To determine exchange coefficients throughout the harbor and the harbor's flushing efficiency, the harbor would be uniformly seeded with a harmless detectable solute such as a fluorescent dye and then sampled periodically at several points in the harbor for a period of several tidal cycles. The initial and subsequent dye concentrations (see Eq. II-7-20) can be measured in situ by a standard fluorometer. The dye Rhodamine WT has been used in a number of harbor flushing studies. (see Callaway 1981; Schwartz and Imberger 1988).

II-7-7. Vessel Interactions

a. Vessel-Generated Waves. As a vessel travels across the water surface a variable pressure distribution develops along the vessel hull. The pressure rises at the bow and stern and drops along the midsection. These pressure gradients, in turn, generate a set of waves that propagate out from the vessel bow and another generally lower set of waves that propagate out from the vessel stern. The heights of the resulting waves depend on the vessel speed, the bow and stern geometry, and the amount of clearance between the vessel hull and channel bottom and sides. The period and direction of the resulting waves depend only on the vessel speed and the water depth. For a detailed discussion of the vessel wave generating process and the resulting wave characteristics see Robb (1952), Sorensen (1973a, 1973b), and Newman (1978).

The pattern of wave crests generated at the bow of a vessel that is moving at a constant speed over deep water is depicted in Figure II-7-40. There are symmetrical sets of *diverging* waves that move obliquely out from the vessel's sailing line and a set of *transverse* waves that propagate along the sailing line. The *transverse* and *diverging* waves meet along the cusp locus lines that form an angle of 19°28' with the sailing line. The largest wave heights are found where the *transverse* and *diverging* waves meet. If the speed of the vessel is increased, this wave crest pattern retains the same geometric form but expands in size as the individual wave lengths (and periods) increase.

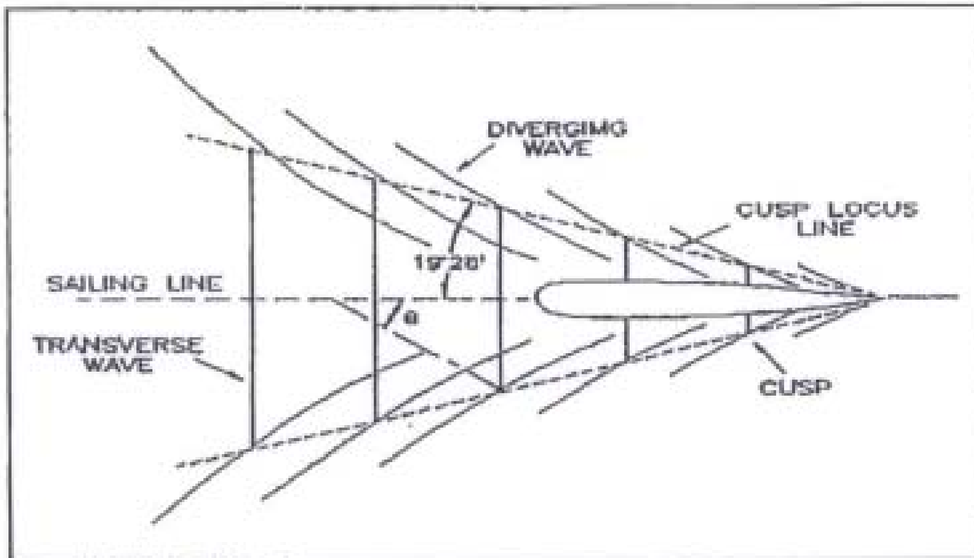


Figure II-7-40. Wave crest pattern generated at a vessel bow moving over deep water

The fixed pattern of wave crests requires that the individual wave celerities C be related to the vessel speed V_s by

$$C = V_s \cos\theta \qquad \text{(II-7-21)}$$

where θ is the angle between the sailing line and the direction of wave propagation (Figure II-7-40). Thus, the *transverse* waves travel at the same speed as the vessel and, in deep water, θ has a value of 35°16' for the *diverging* waves.

The increasing distances from the vessel, diffraction causes the wave crest lengths to continually increase and the resulting wave heights to continually decrease. It can be shown (Havelock 1908) that the wave heights at the cusp points decrease at a rate that is inversely proportional to the cube root of the distance from the vessel's bow (or stern). The *transverse* wave heights at the sailing line decrease at a rate proportional to the square root of the distance aft of the bow (or stern). Consequently, the *diverging* waves become more pronounced with distance from the vessel.

The above discussion applies to deep water, i.e. water depths where the particle motion in the vessel-generated waves does not reach to the bottom. This condition holds for a Froude number less than approximately 0.7, where the Froude number F is defined by

$$F = \frac{V_s}{\sqrt{gd}} \qquad \text{(II-7-22)}$$

As the Froude number increases from 0.7 to 1.0, wave motion is affected by the water depth and the wave crest pattern changes. The cusp locus line angle increases from 19°28' to 90° at a Froude number of one. The *diverging* wave heights increase more slowly than do the *transverse* wave heights, so the latter become more prominent as the Froude number approaches unity. At a Froude number of one, the *transverse* and *diverging* waves have coalesced and are oriented with their crest perpendicular to the sailing line. Most of the wave energy is concentrated in a single large wave at the bow. Owing to propulsion limits (Schofield 1974) most self-propelled vessels can only operate at maximum Froude numbers of about 0.9. Also, as a vessel's speed increases, if the vessel is sufficiently light (i.e. has a shallow draft), hydrodynamic lift may cause the vessel to plane so that there is no significant increase in the height of generated waves for vessel speeds in excess of the speed when planing commences.

For harbor design purposes, one would like to know the direction, period and height of the waves generated by a design vessel moving at the design speed. For Froude numbers up to unity, Weggel and Sorensen (1986) show that the direction of wave propagation θ(in degrees) is given by

$$\theta = 35.27\ (1 - e^{12(F-1)}) \qquad \text{(II-7-23)}$$

Then, from Eq. II-7-21 the *diverging* wave celerity can be calculated, and the wave period can be determined from the linear wave theory dispersion equation.

EXAMPLE PROBLEM II-7-6

FIND:

The period of the *diverging* waves generated by the vessel.

GIVEN:

A vessel is moving at a speed of 10 knots (5.157 meters/second) over water 5 meters deep.

SOLUTION:

The vessel Froude number is

$$F = \frac{5.157}{\sqrt{9.81\ (5)}} = 0.73$$

so Eq. II-7-23 gives a direction of propagation

$$\theta = 35.27\ [1 - e^{12(0.73-1)}] = 33.88°$$

and Eq. II-7-21 gives a wave celerity

$$C = 5.157\ \cos(33.88°) = 4.28\, m/s$$

The linear wave dispersion equation can be written

$$C = \frac{gT}{2\pi} \tanh \frac{2\pi d}{CT}$$

Inserting known values for C,g and d into the dispersion equation leads to a trial solution for T which is found to be 2.8 seconds. This is a typical period for vessel-generated waves and demonstrates why floating breakwaters are usually effective in protecting against vessel waves.

The typical wave record produced by a moving vessel is shown in Figure II-7-41. Most field and laboratory investigations of vessel-generated waves (Sorensen and Weggel 1984; Weggel and Sorensen 1986) report the maximum wave height (H_m see Figure II-7-41) as a function of vessel speed and type, water depth, and distance from the sailing line to where the wave measurement was made. Table II-7-5 (from Sorensen 1973b) provides a tabulation of selected H_m values for a range of vessel characteristics and speeds at different distances from the sailing line. These data are given to indicate the range of typical wave heights that might occur for common vessels and that vessel speed is more important than vessel dimensions in determining the height of the wave generated.

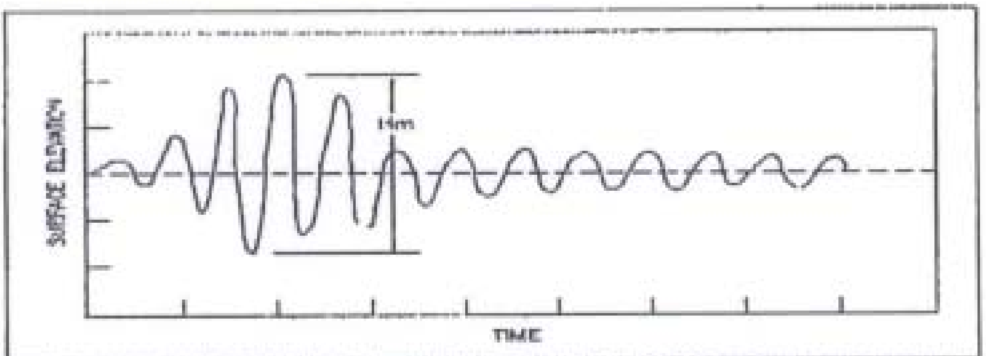


Figure II-7-41. Typical vessel-generated wave record

Table II-7-5
Selected Vessel-Generated Wave Heights (Sorensen 1973b)

Vessel	Speed (m/s)	H_m(m) @30m	H_m(m) @150m
Cabin Cruiser length-7.0m beam-2.5m draft-0.5m	3.1 5.1	0.2 0.4	0.1 0.2
Coast Guard Cutter length-12.2m beam-3.0m draft-1.1m	3.1 5.1 7.2*	0.2 0.5 0.7	0.3
Tugboat length-13.7m beam-4.0m draft-1.8m	3.1 5.1	0.2 0.5	0.1 0.3
Air-Sea Rescue Vessel length-19.5m beam-3.9m draft-0.9m	3.1 5.1 7.2*	0.1 0.4 0.6	0.2 0.3
Fireboat length-30.5m beam-8.5m draft-3.4m	3.1 5.1 7.2	0.1 0.5 0.9	0.1 0.3 0.6
Tanker length-153.6m beam-20.1m draft-8.5m	7.2 9.3		0.5 1.6

Note: The above data are from tests conducted at water depths ranging from 11.9 to 12.8 meters.
* denotes that the vessel was starting to plane.

A number of quasi-empirical procedures for predicting vessel-generated wave heights have been published (Sorensen 1986; Sorensen 1989 for a summary). Most procedures are restricted to a certain class or classes of vessels and specific channel conditions. A comparison (Sorensen 1989) of predicted H_m values for selected vessel speeds and water depths showed a significant variation among the results predicted by the various procedures. The best approach for design analyses appears to be to review the published vessel wave measurement data to compare with the vessel, vessel speed and channel conditions that most closely approach the design condition and select a conservative value of H_m from these data. If this is not possible, then the values in Table II-7-5 can be used as a rough estimate for the different types of vessels.

b. Vessel motions.

(1) Response to waves. Wave action will excite a floating vessel to oscillate in one or more of six components of motion or degrees of freedom. These are translation in the three coordinate directions (surge, sway and heave) and rotation around the three principal axes (roll, pitch and yaw). Which of these motion components is excited and to what extent depends primarily on the direction of wave incidence relative to the primary vessel axes and on the incident wave frequency spectrum compared to the resonant frequencies of the six motion components (Wehausen 1971). If the vessel is moored, the arrangement of the mooring lines and their taughtness will influence the resonant periods and the response amplitudes of the vessel motions. If the vessel is moving, the effective or encounter period of wave agitation is the wave period relative to the ship rather than to a fixed observation point. Wave mass transport will also cause a slow drift of the vessel in the direction of wave propagation.

Small vessels, such as the recreational vessels found in marinas, will commonly respond to shorter wind-wave periods. An analytical study coupled with some field measurements for seven small boats (Raichlen 1968) indicated that the periods of free oscillation were less than ten seconds. Larger sea-going deep-draft vessels, depending on the oscillation mode being excited, will respond to the entire range of wind-wave periods. Field measurements by van Wyk (1982) on ships having lengths around 250 to 300 m and beams around 40 m found maximum roll and pitch responses at encounter periods between 10 and 12 seconds. By proper design of the mooring system, the periods and amplitudes of vessel motion can be significantly modified.

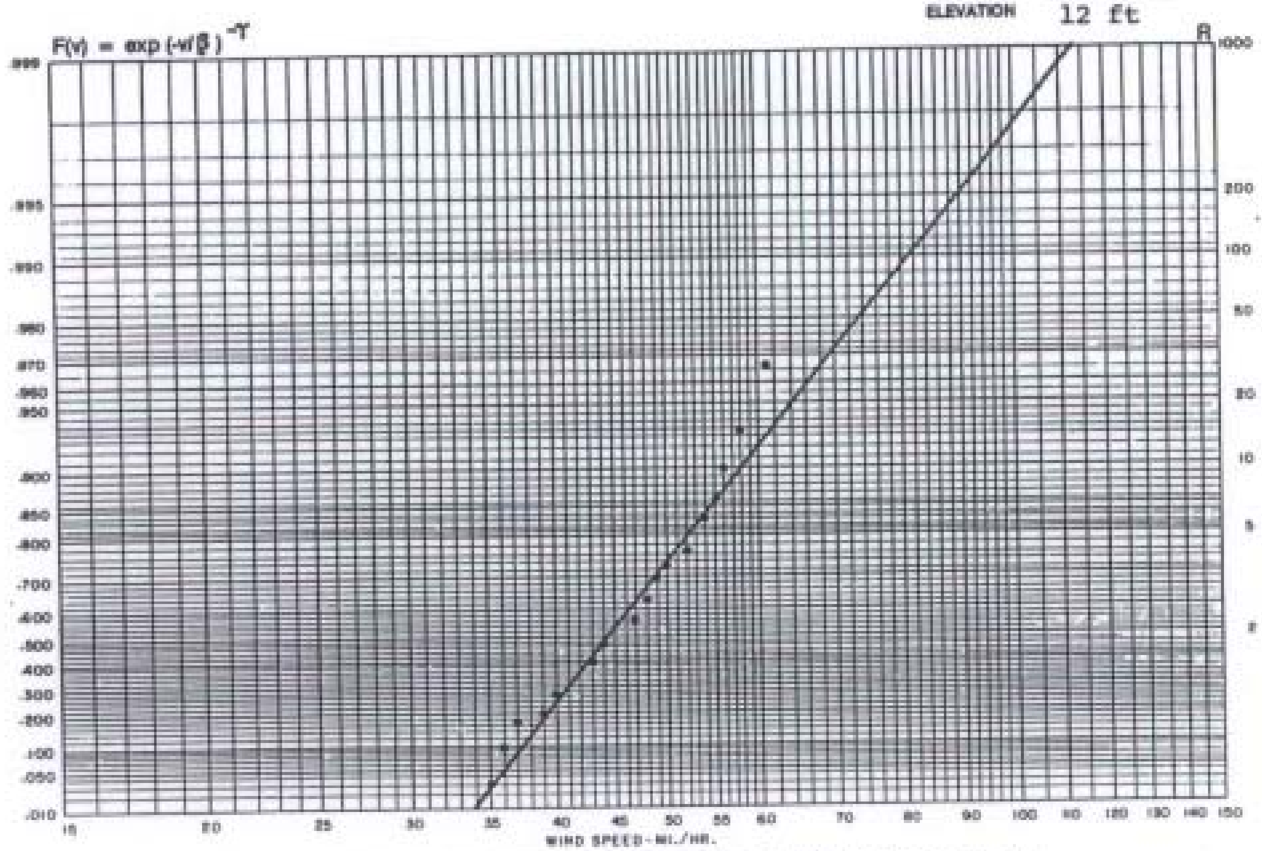
The wave-induced lateral and vertical motions of the design vessel will affect the required channel horizontal and depth dimensions respectively. The problem of wave-induced vessel oscillations has been addressed by analytical/numerical means (Anderson 1979; Madsen, et al. 1980, and Isaacson and Mercer 1982). These efforts usually employ small amplitude monochromatic waves and some limitations on vessel geometry and the incident wave directions relative to the vessel.

Some field measurement programs have been made that yield valuable design information. Wang and Noble (1982) describe an investigation of vessels entering the Columbia River

FIGURE 9

J U N E A U

LATITUDE 58 22'N
LONGITUDE 134 35'W
ELEVATION 12 ft



MAXIMUM - VALUE PROBABILITY PAPER, FISHER - TIPPET TYPE II DISTRIBUTION

$\bar{v}$ = 46.4 σ^2 = 63.2 σ = 8.0

μ = 36 β = 42 γ = 6.9

PERIOD OF RECORD: 1949-1978

EXTREME VALUE PREDICTIONS IN MILES PER HOUR

	RETURN PERIOD IN YEARS					
	25	50	100	250	500	1000
WIND ESTIMATE	66.8	73.9	81.8	93.5	103.4	114.3

"Extreme Wind Prediction for First Order Weather stations in AK"
Arctic Environment Information and Data Center, UAF,
Alaska Climate Center Technical Note #1 1984

Chance of exceedance

Return Period	Probability	Chance of happening during a given number of years										
		1	2	5	10	20	25	50	100	200	500
2	50%	50%	75%	97%	100%	100%	100%	100%	100%	100%	100%
3	33%	33%	56%	87%	98%	100%	100%	100%	100%	100%	100%
4	25%	25%	44%	76%	94%	100%	100%	100%	100%	100%	100%
5	20%	20%	36%	67%	89%	99%	100%	100%	100%	100%	100%
6	17%	17%	31%	60%	84%	97%	99%	100%	100%	100%	100%
7	14%	14%	27%	54%	79%	95%	98%	100%	100%	100%	100%
8	13%	13%	23%	49%	74%	93%	96%	100%	100%	100%	100%
9	11%	11%	21%	45%	69%	91%	95%	100%	100%	100%	100%
10	10%	10%	19%	41%	65%	88%	93%	99%	100%	100%	100%
20	5%	5%	10%	23%	40%	64%	72%	92%	99%	100%	100%
25	4%	4%	8%	18%	34%	56%	64%	87%	98%	100%	100%
50	2.0%	2.0%	4.0%	10%	18%	33%	40%	64%	87%	98%	100%
100	1.0%	1.0%	2.0%	4.9%	10%	18%	22%	39%	63%	87%	99%
200	0.5%	0.5%	1.0%	2.5%	4.9%	10%	12%	22%	39%	63%	92%
500	0.2%	0.2%	0.4%	1.0%	2.0%	3.9%	4.9%	10%	18%	33%	63%
1,000	0.1%	0.1%	0.2%	0.5%	1.0%	2.0%	2.5%	4.9%	10%	18%	39%
10,000	0.01%	0.01%	0.02%	0.05%	0.1%	0.2%	0.2%	0.5%	1.0%	2.0%	4.9%
100,000	0.001%	0.001%	0.002%	0.005%	0.01%	0.02%	0.02%	0.05%	0.1%	0.2%	0.5%
1,000,000	0.0001%	0.0001%	0.0002%	0.0005%	0.001%	0.002%	0.002%	0.005%	0.01%	0.02%	0.05%

$$J = 1 - (1-p)^n$$

where J = probability of occurence in period
P = probability of occurence in a given year
N = Number of years in a period

Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants
1506 West 36th Avenue Anchorage, Alaska 99503 (907) 561-1011 Fax (907) 563-4220

Memorandum

To: File | Project No.: 02056.02

From: Jennifer Wilson | Date: October 3, 2002

Re: *Areas Identified for Detailed Study*

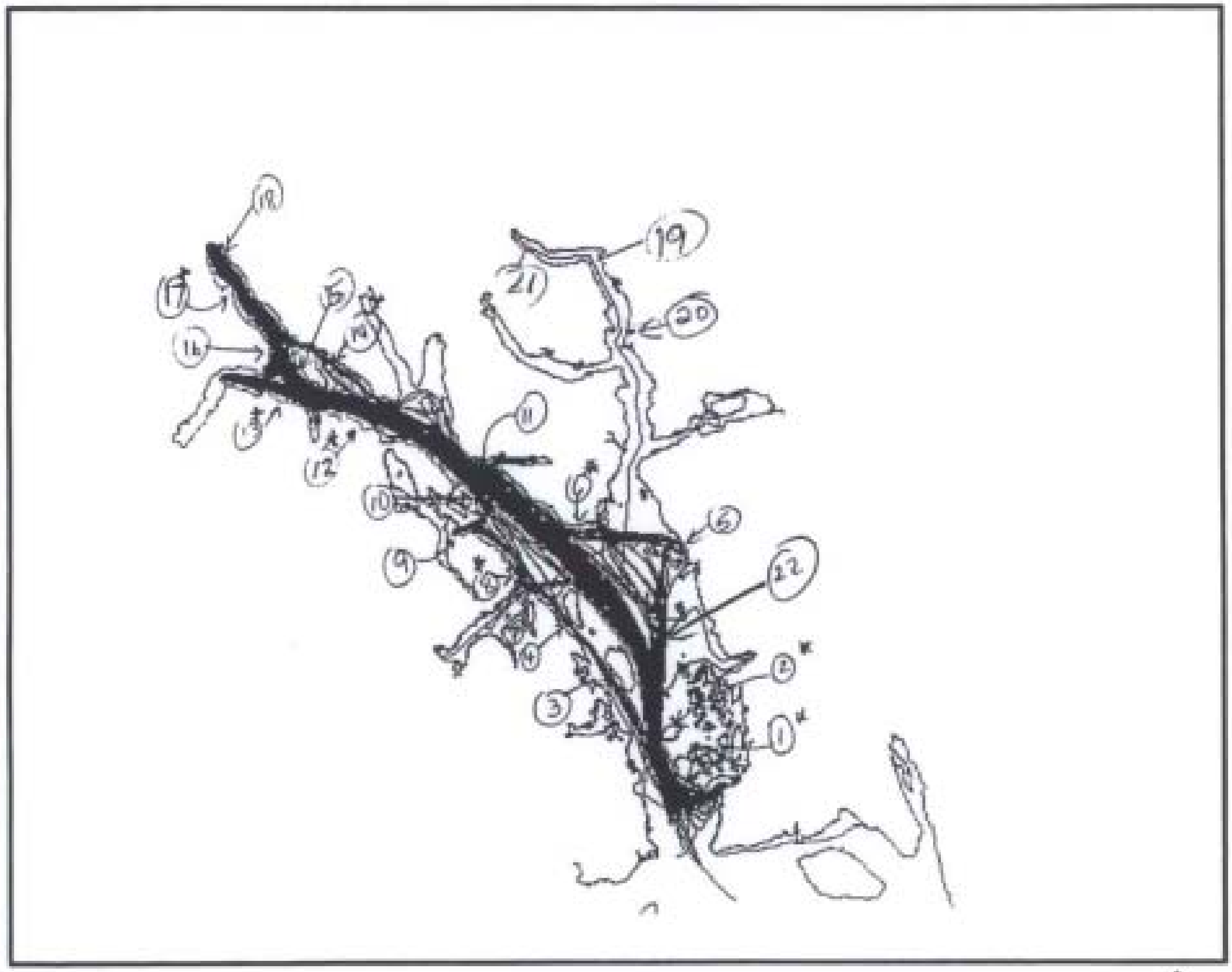
Project: Glacier Bay National Park and Preserve Vessel Quotas and Operating Requirements Environmental Impact Statement, Appendix F Technical Memorandum

---

The attached document, *Areas Identified for Detailed Study*, provides the maps and data used to determine the sites where vessel traffic was within 2,000 feet of shore. This may be due to channel constriction or operation decisions. The attachment includes several maps with vessel track information.

ESRI ArcExplorer 2.0

Vessel Traffic



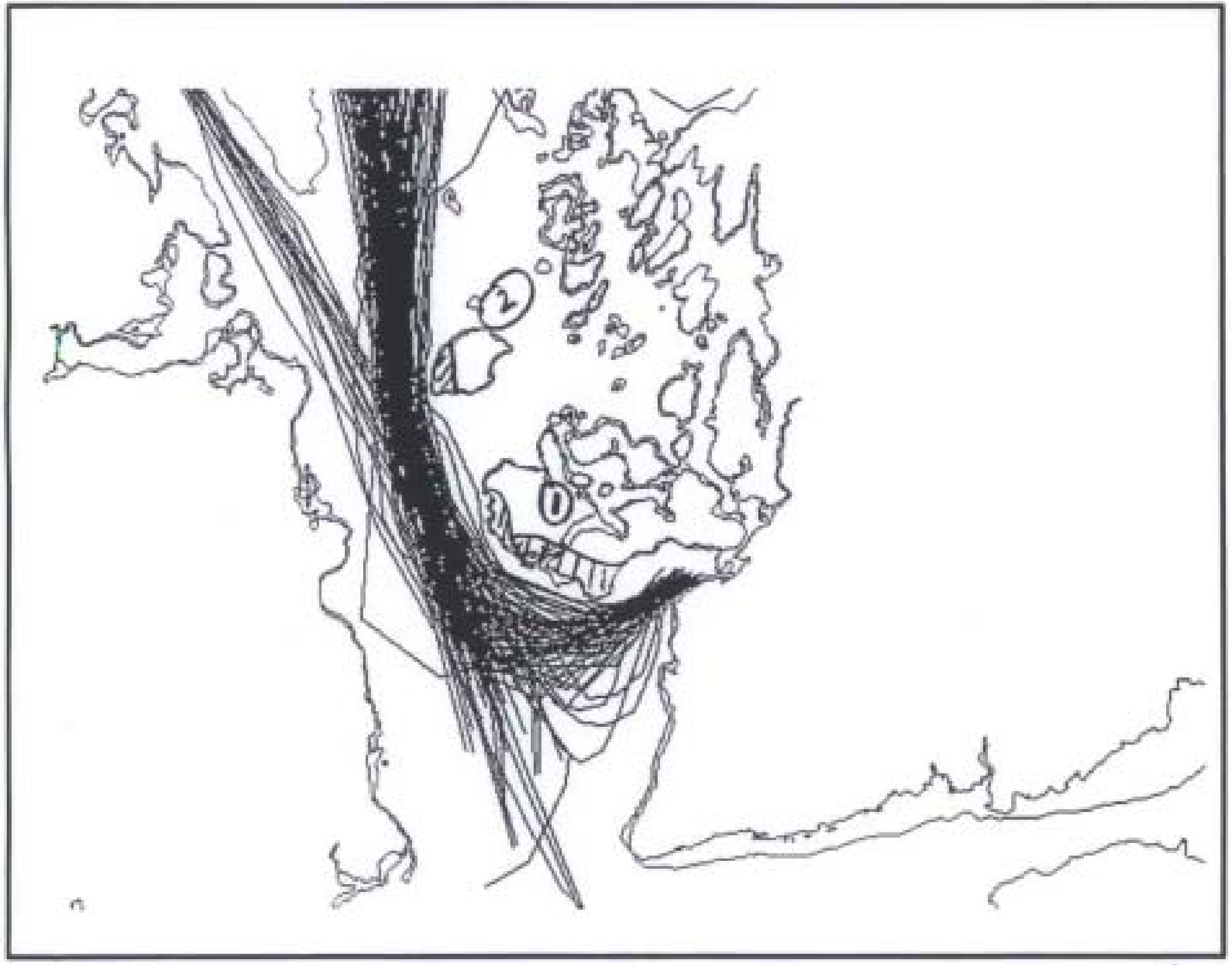
bt.dwg
oceanog_line_utm
NOAA_C~2

N

Friday, Jul 12 2002

ESRI ArcExplorer 2.0

Sitadaday Narrows



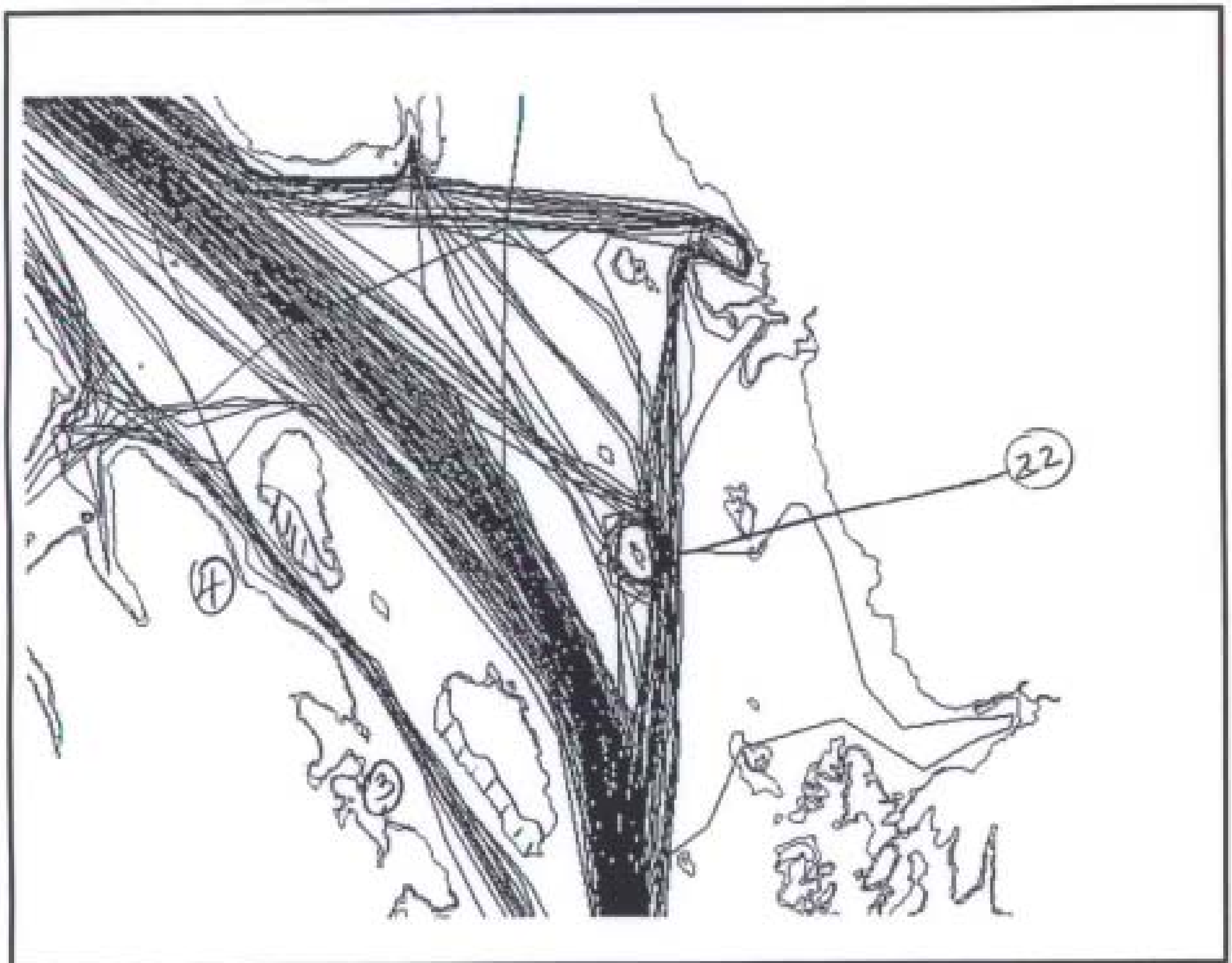
bt.dwg
oceanog_line_utm
NOAA_C~2

N

Friday, Jul 12 2002

ESRI ArcExplorer 2.0

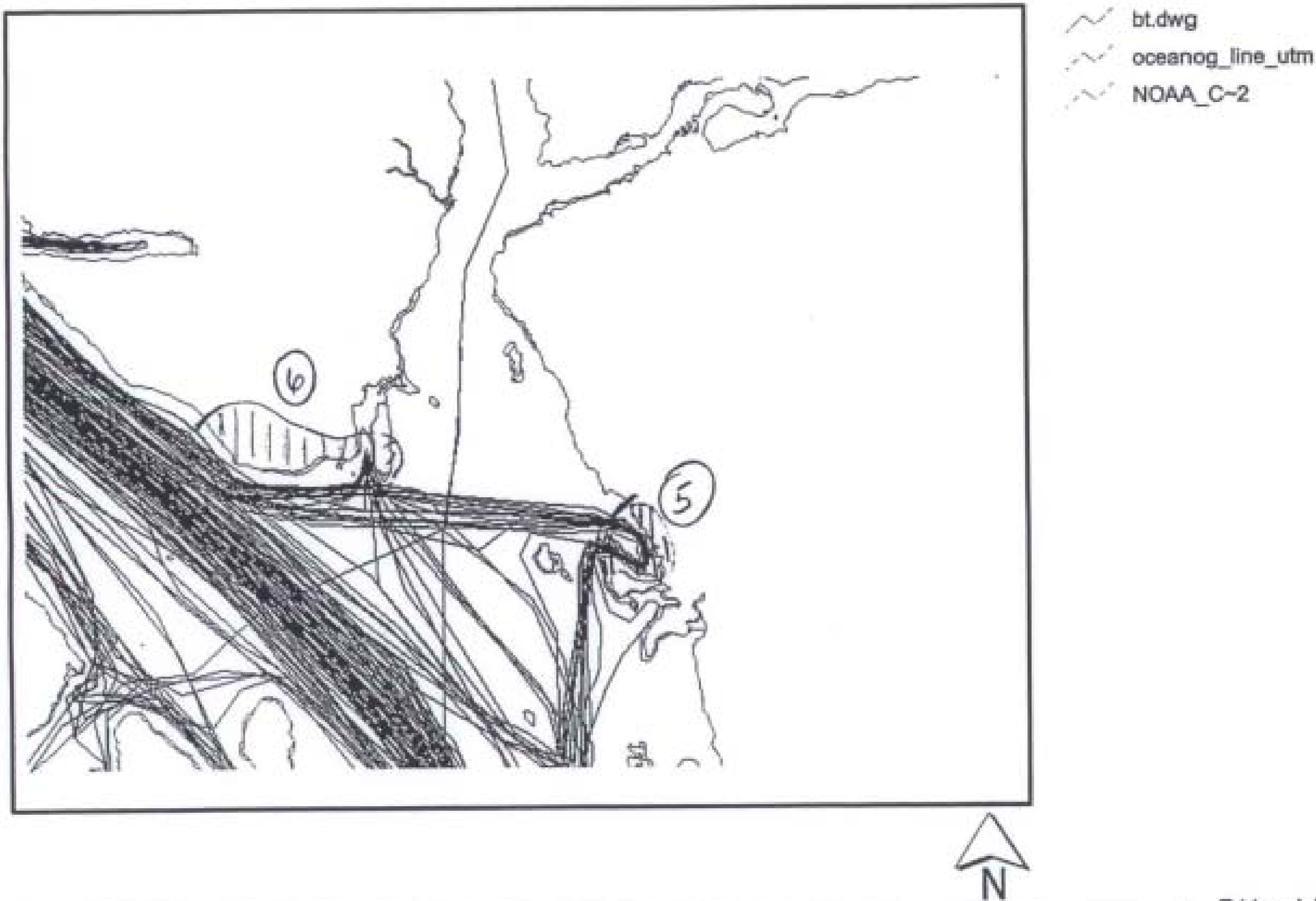
Whidbey Passage



Friday, Jul 12 2002

ESRI ArcExplorer 2.0

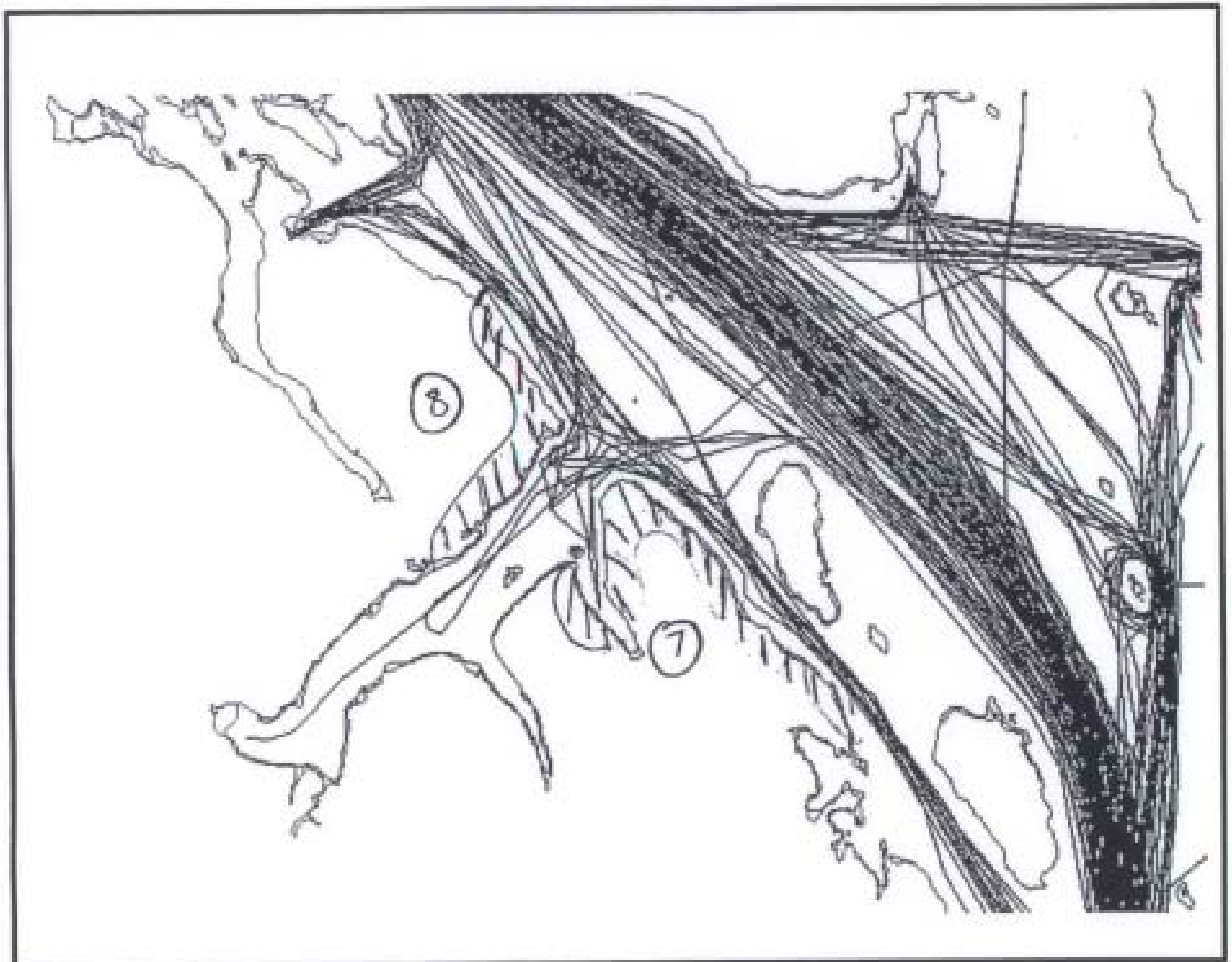
Lower Muir Inlet



Friday, Jul 12 2002

ESRI ArcExplorer 2.0

Geikie Inlet



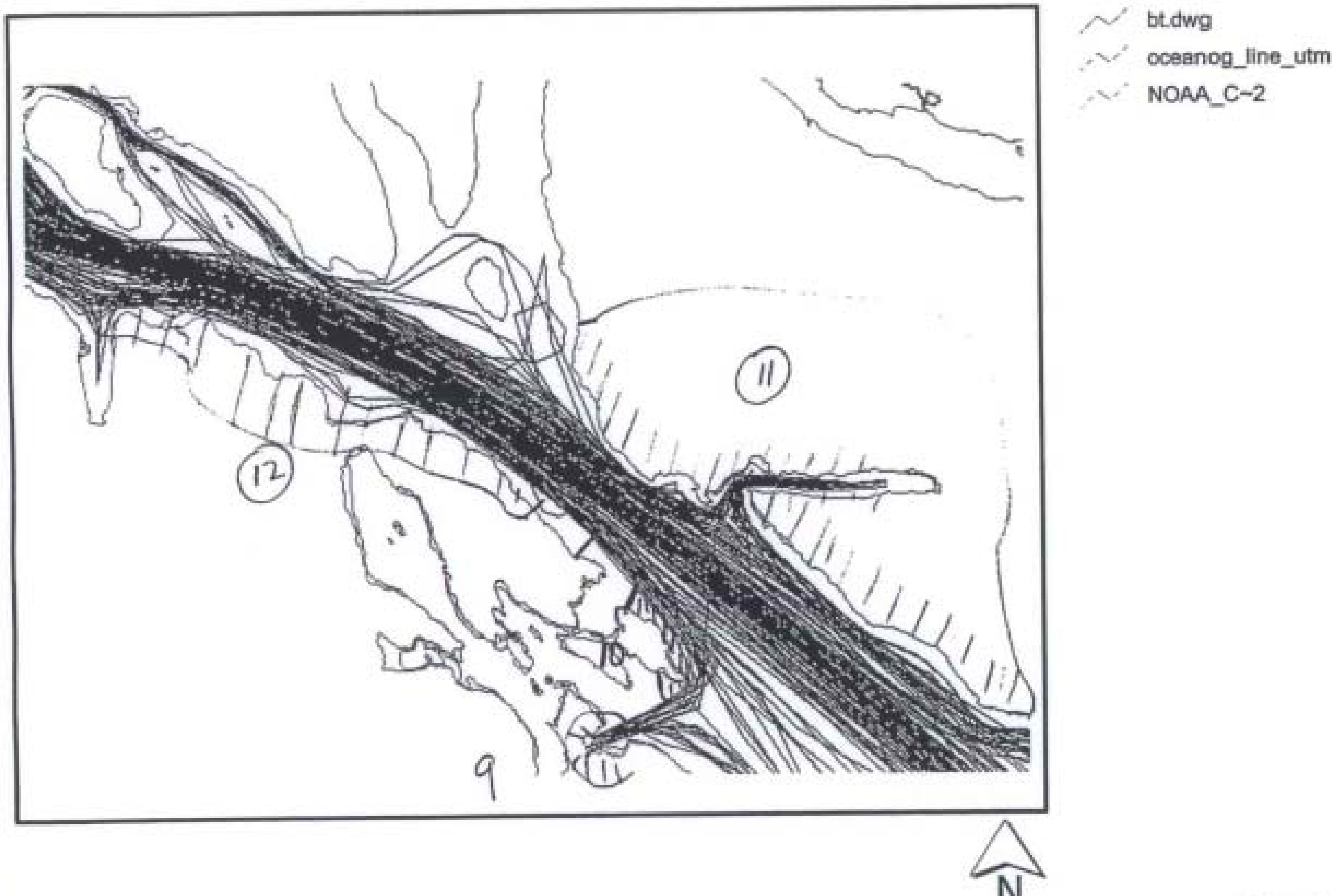
bt.dwg
oceanog_line_utm
NOAA_C-2

N

Friday, Jul 12 2002

ESRI ArcExplorer 2.0

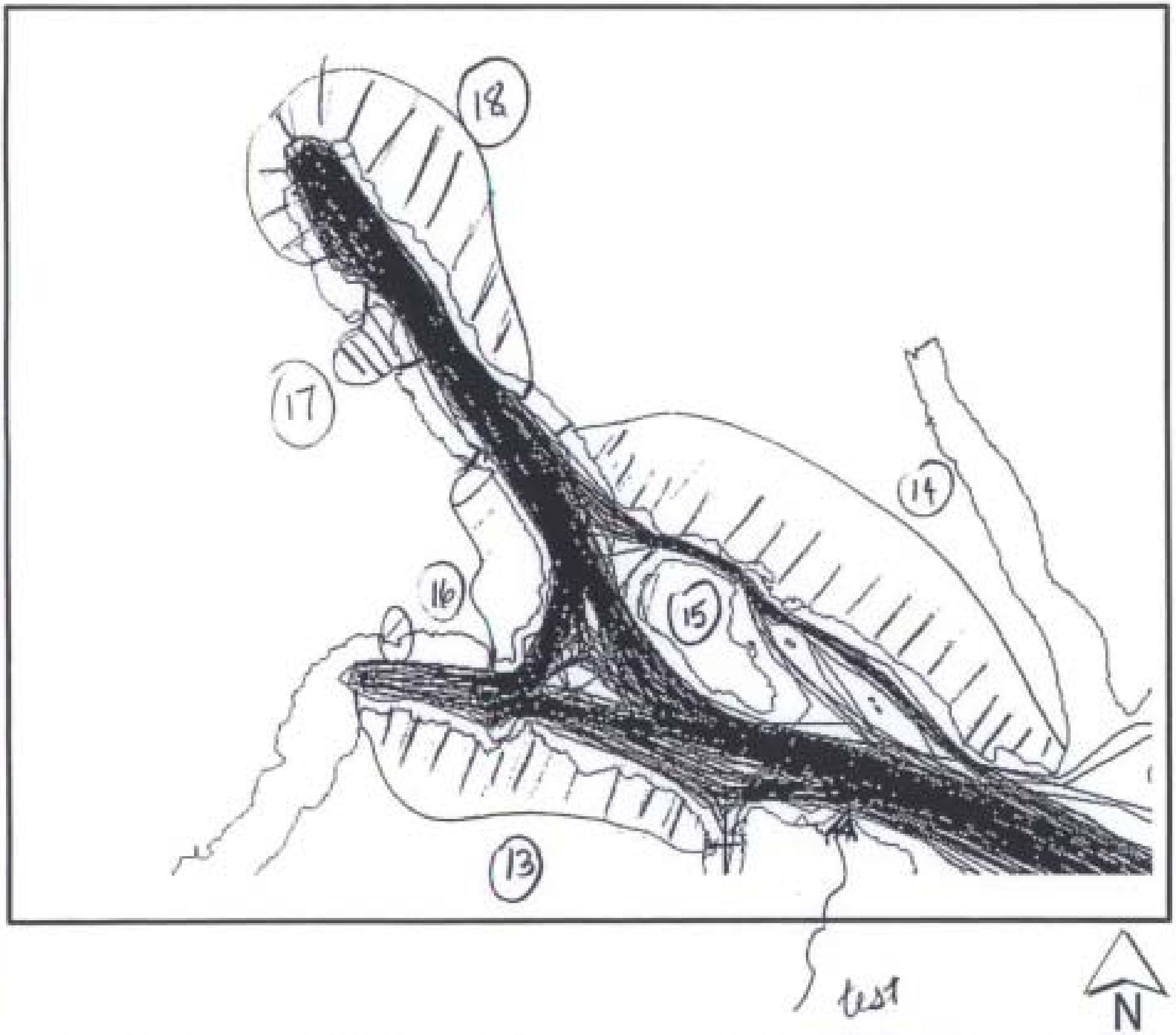
Tidal Inlet



Friday, Jul 12 2002

ESRI ArcExplorer 2.0

Tarr Inlet



bt.dwg
oceanog_line_utm
NOAA_C~2

Friday, Jul 12 2002

Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants
1506 West 36th Avenue Anchorage, Alaska 99503 (907) 561-1011 Fax (907) 563-4220

Memorandum

To: File Project No.: 02056.02

From: Jennifer Wilson Date: October 3, 2002

Re: *Example Calculations*

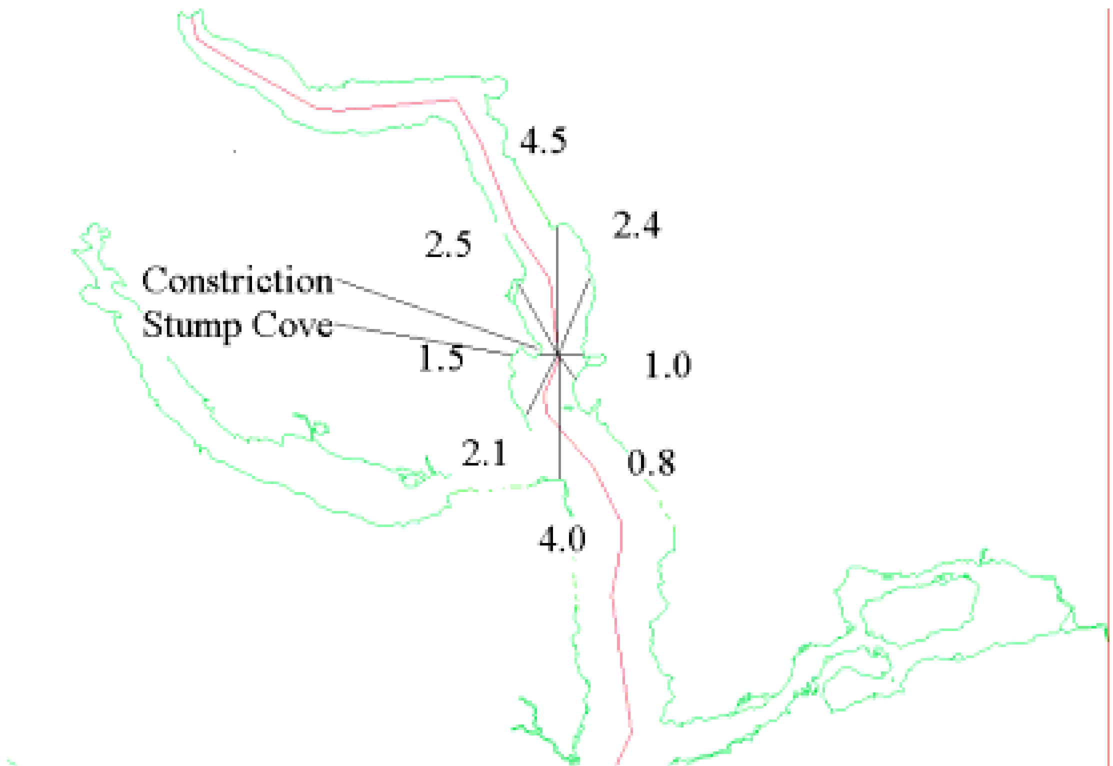
Project: Glacier Bay National Park and Preserve Vessel Quotas and Operating Requirements Environmental Impact Statement, Appendix F Technical Memorandum

---

The attached document, *Example Calculations*, provides example calculations on vessel wake energy for Site 11 and Site 20 in Glacier Bay proper. These calculations use the 1996 vessel use-days under Alternative 1 (No Action Alternative).

Example Calculation 1. Upper Muir Inlet

Winds from 50 degrees



Site 20. Stump Cove near Muir Inlet, fetch distances in miles.

From the wind analysis, there are three categories of wind with values for direction 50 degrees, and the following probablilities of occurence in each category.

Category 1: 1 to 9.999 knots with probability of occurence of 5.6%
Category 2: 10 to 19.999 knots with probability of occurence of 0.34%
Category 3: 20 to 29.999 knots with probability of occurence of 0.0034%

$P_1 := 0.056237$

$P_2 := 0.003371$

$P_3 := 0.000034$

For the fetch shown in the drawing above, using CEDAS for restricted open water fetches, the wind direction of 50 degrees, a duration of 1 hour, the average wind velocity of 5 knots, we find that a significant wave of height 0.13 foot will be generated with a significant period of 0.8 sec.

With the average wind velocity of 15 knots, we find that a significant wave height of 0.68 feet with the significant wave period of 1.7 sec will be generated.

With the average wind velocity of 25 knots, we find that a significant wave height of 1.33 feet with the significant wave period of 2.27 sec will be generated.

The general direction of the waves are 52 degrees in both instances and the shorelines affected will be oriented perpendicular to this direction.

$$H_{MO1} := 0.13 \qquad T_{P1} := 0.8s$$

$$H_{MO2} := 0.68 \qquad T_{P2} := 1.7s$$

$$H_{MO3} := 1.33 \qquad T_{P3} := 2.27s$$

The expected number of waves in an hourly wind event:

$$E_1 := \frac{1}{T_{P1}} \cdot 60 \frac{sec}{min} \cdot 60 \frac{min}{hr} \qquad E_1 = 4.5 \times 10^3 \, hr^{-1}$$

$$E_2 := \frac{1}{T_{P2}} \cdot 60 \frac{sec}{min} \cdot 60 \frac{min}{hr} \qquad E_2 = 2.118 \times 10^3 \, hr^{-1}$$

$$E_3 := \frac{1}{T_{P3}} \cdot 60 \frac{sec}{min} \cdot 60 \frac{min}{hr} \qquad E_3 = 1.586 \times 10^3 \, hr^{-1}$$

Two shores most directly affected by the wind from 50 degrees are labeled as Beach A and Beach B in the figure below.

If Beach A were directly perpendicular to the direction of the waves generated by the 50 degree wind in this fetch, the energy from the 50 degree winds can be seen to be proportional to $n_1 + n_2$ where:

$$n_1 := H_{MO1}{}^2 \cdot P_1 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_1 \qquad n_1 = 3.746 \times 10^4 \, yr^{-1}$$

$$n_2 := H_{MO2}{}^2 \cdot P_2 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_2 \qquad n_2 = 2.892 \times 10^4 \, yr^{-1}$$

$$n_3 := H_{MO3}{}^2 \cdot P_3 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_3 \qquad n_3 = 835.532 \, yr^{-1}$$

Where the term $(P_1(24)\ 365\ hr/yr)E_1$ represents the expected value of the number of hourly wind events per year. The n_i's represent the energy from the waves generated by wind in this one direction predicted by linear wave theory.

Beach A will be affected only by winds from 50 degrees and from 340 degrees, as the following analysis shows. Furthermore, wave energies directly perpendicular to shore must be calculated.

Since Beach A is not directly perpendicular to the direction of the waves, the values n_1, n_2 and n_3 must be multiplied by the sin of the angle between the beach and the wave ray to get the component or part of the energy which is directed perpendicular to the beach. The energy directed parallel to shore is not added into the calculation. Wind wave energy parallel to shore adds to the longshore sediment transport, as does tidal energy.

The approximate azimuth of Beach A is 329 degrees. The waves generated by 50 degree winds in this particular fetch will have a propagation direction of 52 degrees. The angle between the beach face and the wave ray is thus 360-329+52 or 83 degrees.

The energy perpendicular to shore from these waves is thus found from:

$\theta := 83\text{deg}$

$$n_1 := H_{MO1}{}^2 \cdot P_1 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_1 \cdot \sin(\theta) \qquad n_1 = 3.719 \times 10^4\, yr^{-1}$$

$$n_2 := H_{MO2}{}^2 \cdot P_2 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_2 \cdot \sin((\theta)) \qquad n_2 = 2.87 \times 10^4\, yr^{-1}$$

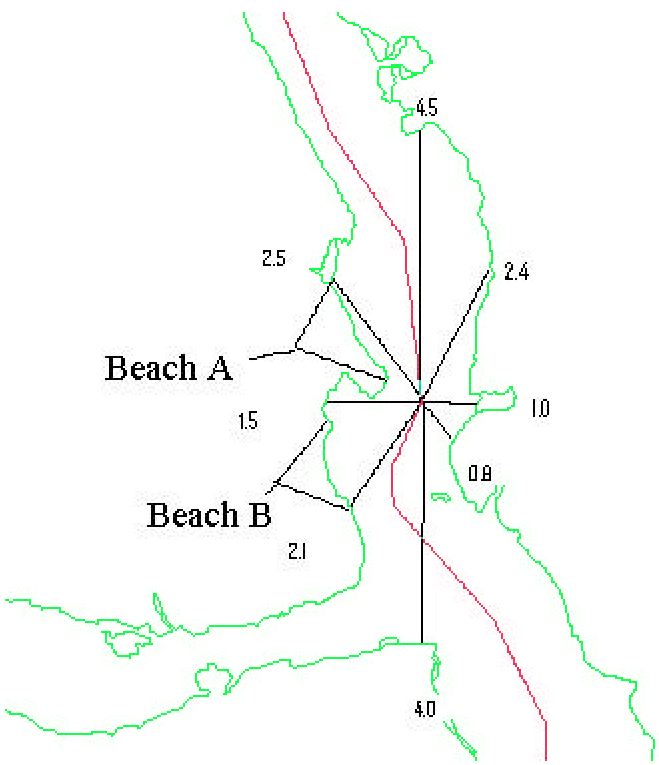
$$n_3 := H_{MO3}{}^2 \cdot P_3 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_3 \cdot \sin((\theta)) \qquad n_3 = 829.304\, yr^{-1}$$

Let the total energy per year perpendicular to Shore A due to waves from winds coming from 50 degrees be

$$E_{50} := n_1 + n_2 + n_3 \qquad E_{50} = 6.672 \times 10^4\, yr^{-1}$$

To complete the analysis, this process is repeated for the other wind directions.

Winds from 130 deg



Beaches in Site 20. Two of the Beaches Analyzed in Site 20.

Beach A, may be affected by winds from 130 degrees, with the same limited fetch. It is necessary to use ACES to determine the direction of the waves that winds from 130 degrees will produce in this fetch. In general, a fetch modifies the wave direction.

The direction of the waves according to ACES is 170 degrees. Since θ=360-329+170=201. These waves will not be incident on Beach A.

Winds from 200, 260 and 340 deg

Wind directions 200, 260 and 340 produce waves in this fetch of incident angles 185, 245 and 353, according to ACES with the fetch in Upper Muir Inlet near Stump Cove. Of these, only the last wind direction will affect Beach A and

$\theta := (353 - 329)\mathrm{deg}$ $\qquad\qquad$ $\theta = 24\,\mathrm{deg}$

Site 20 Beach A is sheltered by the topography and coastal features of the site from wave attack in the other directions.

From the wind analysis, there are three categories of wind with values for direction 340 degrees, and the following probablilities of occurence in each category.

Category 1: 1 to 9.999 knots with probability of occurence of 18.07% $\qquad P_1 := .180695$

Category 2: 10 to 19.999 knots with probability of occurence of .9195% $\qquad P_2 := .009195$

Category 3: 20 to 29.999 knots with probability of occurence of 0.009% $\qquad P_3 := 0.000009$

For the fetch shown in the drawings above, using CEDAS for restricted open water fetches, the wind direction of 340 degrees, a duration of 1 hour, the average wind velocity of 5 knots, we find that a significant wave of height 0.13 foot will be generated with a significant period of 0.79 sec.

With the average wind velocity of 15 knots, we find that a significant wave height of .66 feet with the significant wave period of 1.69 sec will be generated.

With the average wind velocity of 25 knots, we find that a significant wave height of 1.49 feet with a significant wave period of 2.47 sec will be generated.

The general direction of the waves are 353 degrees. θ=24 deg

$H_{MO1} := 0.13$ $\qquad\qquad$ $T_{P1} := 0.79s$

$H_{MO2} := 0.66$ $\qquad\qquad$ $T_{P2} := 1.69s$

$H_{MO3} := 1.49$ $\qquad\qquad$ $T_{P3} := 2.47s$

The expected number of waves in an hourly wind event:

$$E_1 := \frac{1}{T_{P1}}\cdot 60\frac{\mathrm{sec}}{\mathrm{min}}\cdot 60\frac{\mathrm{min}}{\mathrm{hr}} \qquad E_1 = 4.557\times 10^3\,\mathrm{hr}^{-1}$$

$$E_2 := \frac{1}{T_{P2}}\cdot 60\frac{\mathrm{sec}}{\mathrm{min}}\cdot 60\frac{\mathrm{min}}{\mathrm{hr}} \qquad E_2 = 2.13\times 10^3\,\mathrm{hr}^{-1}$$

$$E_3 := \frac{1}{T_{P3}}\cdot 60\frac{\mathrm{sec}}{\mathrm{min}}\cdot 60\frac{\mathrm{min}}{\mathrm{hr}} \qquad E_3 = 1.457\times 10^3\,\mathrm{hr}^{-1}$$

$\theta := 24\mathrm{deg}$

$$m_1 := H_{MO1}{}^2\cdot P_1\cdot 24\cdot 365\frac{\mathrm{hr}}{\mathrm{yr}}\cdot E_1\cdot\sin(\theta) \qquad m_1 = 4.958\times 10^4\,\mathrm{yr}^{-1}$$

$$m_2 := H_{MO2}{}^2 \cdot P_2 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_2 \cdot \sin(\theta) \qquad m_2 = 3.04 \times 10^4\, yr^{-1}$$

$$m_3 := H_{MO3}{}^2 \cdot P_3 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_3 \cdot \sin(\theta) \qquad m_3 = 103.762\, yr^{-1}$$

Let the total energy per year perpendicular to Beach A due to waves from winds coming from 340 degrees be

$$E_{340} := m_1 + m_2 + m_3$$

Calculation of N

A conversion value to convert the maximum wave height of a wave state to the moment magnitude wave height is 1.8, hence let

$H_{max} := 1$ The design vessel wave height

$$H_{MOV} := \frac{H_{max}}{1.8} \qquad H_{MOV} = 0.556$$

Define V to be the number of vessels "use days" in Glacier Bay per season.

Not every vessel entering Glacier Bay will cause a wake which is incident on Beach A in the above example. Of the 241 total vessel tracks, 2 were counted within 2000 feet of Site 20, Beach A.

$V := \frac{2908}{yr}$ This is the current number of "use days" for permitted vessel entries into Glacier Bay. (refered to as Alternative 1)

$$A := V \cdot \frac{2}{241} \qquad A = 24.133\, yr^{-1}$$

once every .3 days during the 3 month season.

Using this calculation as the basis for the vessel waves which affect each site assumes that the 241 vessel tracks provided by Glacier Bay National Park represent a statistically significant sampling of all vessels which enter the Bay. In fact, we know this is not the case, since the tracks provided include only tour vessels, charter vessels and cruise ships. However the assumption is conservative, because the sampling includes the largest vessels, which are also the vessels which produce the largest wakes.

The value of N for the site would then be:

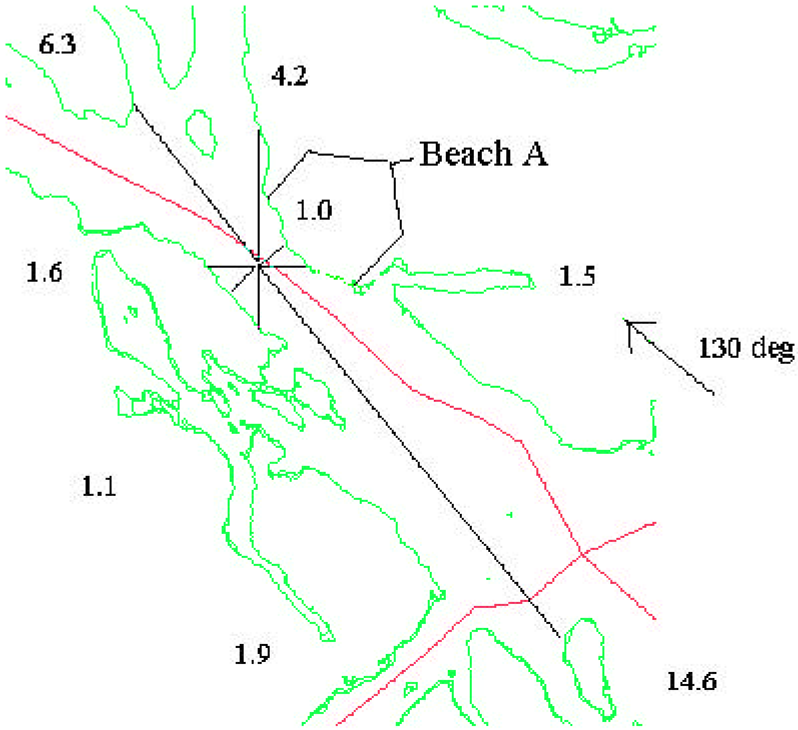
$N := \frac{H_{MOV}{}^2 \cdot 15 \cdot A}{E_{50} + E_{340}}$ where the value of 15 represents the number of waves per vessel wake.

$$N = 7.611 \times 10^{-4}$$

This is a negligible vessel wake potential.

Example 2

Wave analysis of site 11



Site 11, Beach A, Lower West Arm near Tidal Inlet, fetch distances in miles.

Beach A will not be affected by 50 degree winds.

Beach A has a beach face oriented at azimuth angle of 309 degrees. Wave directions which will be incident on Beach A will be in the range of 129 to 309 degrees.

Using ACES with the fetch shown in the figure above, wave directions given wind directions are

130 degrees - waves at 134 degrees (include)
200 degrees - waves at 153 degrees (include)
260 degrees - waves at 299 degrees (include)
340 degrees - waves at 324 degrees (no effect)

Winds from 130 degrees

From the wind analysis, there are two categories of wind with values for direction 130 degrees, and the following probablilities of occurence in each category.

Category 1: 1 to 9.999 knots with probability of occurence of 20.8%
Category 2: 10 to 19.999 knots with probability of occurence of 4.51%
Category 3: 20 to 29.999 knots with probability of occurence of 0.28%

$P_1 := .208013$

$P_2 := 0.0454$

$P_3 := 0.002845$

For the fetch shown in the drawing above, using CEDAS for restricted open water fetches, the wind direction of 50 degrees, a duration of 1 hour, the average wind velocity of 5 knots, we find that a significant wave of height 0.15 foot will be generated with a significant period of 0.86 sec.

With the average wind velocity of 15 knots, we find that a significant wave height of 0.80 feet with the significant wave period of 1.85 sec will be generated.

With the average wind velocity of 25 knots, we find that a significant wave height of 1.83 feet with a significant wave period of 2.72 sec will be generated.

$H_{MO1} := 0.15 \qquad T_{P1} := 0.86s$

$H_{MO2} := 0.8 \qquad T_{P2} := 1.85s$

$H_{MO3} := 1.83 \qquad T_{P3} := 2.72s$

The expected number of waves in an hourly wind event:

$$E_1 := \frac{1}{T_{P1}} \cdot 60 \frac{sec}{min} \cdot 60 \frac{min}{hr} \qquad E_1 = 4.186 \times 10^3 \, hr^{-1}$$

$$E_2 := \frac{1}{T_{P2}} \cdot 60 \frac{sec}{min} \cdot 60 \frac{min}{hr} \qquad E_2 = 1.946 \times 10^3 \, hr^{-1}$$

$$E_3 := \frac{1}{T_{P3}} \cdot 60 \frac{sec}{min} \cdot 60 \frac{min}{hr} \qquad E_3 = 1.324 \times 10^3 \, hr^{-1}$$

The general direction of the waves are 134 degrees in all instances and the shoreline A is oriented at an angle of 309 degrees.

$\theta := [134 - (309 - 180)]deg \quad \theta = 5 \, deg$

$\sin(\theta) = 0.087$

$$m_1 := H_{MO1}{}^2 \cdot P_1 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_1 \cdot \sin(\theta) \qquad m_1 = 1.496 \times 10^4 \, yr^{-1}$$

$$m_2 := H_{MO2}{}^2 \cdot P_2 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_2 \cdot \sin(\theta) \qquad m_2 = 4.317 \times 10^4 \, yr^{-1}$$

$$m_3 := H_{MO3}{}^2 \cdot P_3 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_3 \cdot \sin(\theta) \qquad m_3 = 9.628 \times 10^3 \, yr^{-1}$$

$$E_{130} := m_1 + m_2 + m_3$$

Winds from 200 degrees

From the wind analysis, there are three categories of wind with values for direction 200 degrees, and the following probablilities of occurence in each category.

Category 1: 1 to 9.999 knots with probability of occurence of 11.55%
Category 2: 10 to 19.999 knots with probability of occurence of .70%
Category 3: 20 to 29.999 knots with probability of occurence of .0168%

$P_1 := .115498$

$P_2 := 0.006978$

$P_3 := 0.000168$

For the fetch shown in the drawing above, using CEDAS for restricted open water fetches, the wind direction of 200 degrees, a duration of 1 hour, the average wind velocity of 5 knots, we find that a significant wave of height 0.08 foot will be generated with a significant period of 0.63 sec.

With the average wind velocity of 15 knots, we find that a significant wave height of 0.41 feet with the significant wave period of 1.36 sec will be generated.

With the average wind velocity of 25 knots, we find that a significant wave height of .93 feet with a significant wave period of 1.99 sec will be generated.

$H_{MO1} := 0.08 \quad T_{P1} := 0.63s$

$H_{MO2} := 0.41 \quad T_{P2} := 1.36s$

$H_{MO3} := .93 \quad T_{P3} := 1.99s$

The expected number of waves in an hourly wind event:

$$E_1 := \frac{1}{T_{P1}} \cdot 60 \frac{sec}{min} \cdot 60 \frac{min}{hr} \qquad E_1 = 5.714 \times 10^3 \, hr^{-1}$$

$$E_2 := \frac{1}{T_{P2}} \cdot 60 \frac{sec}{min} \cdot 60 \frac{min}{hr} \qquad E_2 = 2.647 \times 10^3 \, hr^{-1}$$

$$E_3 := \frac{1}{T_{P3}} \cdot 60 \frac{sec}{min} \cdot 60 \frac{min}{hr} \qquad E_3 = 1.809 \times 10^3 \, hr^{-1}$$

The general direction of the waves are 153 degrees in all instances and the since shoreline A is oriented at an angle of 309 degrees degrees.

$$\theta := [153 - (309 - 180)]deg$$

$$\theta = 24\,deg \qquad \sin(\theta) = 0.407$$

$$m_1 := H_{MO1}{}^2 \cdot P_1 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_1 \cdot \sin(\theta) \qquad m_1 = 1.505 \times 10^4 \, yr^{-1}$$

$$m_2 := H_{MO2}{}^2 \cdot P_2 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_2 \cdot \sin(\theta) \qquad m_2 = 1.106 \times 10^4 \, yr^{-1}$$

$$m_3 := H_{MO3}{}^2 \cdot P_3 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_3 \cdot \sin(\theta) \qquad m_3 = 936.574 \, yr^{-1}$$

$$E_{200} := (m_1 + m_2 + m_3)$$

$$E_{200} = 2.705\times 10^4\,yr^{-1}$$

Winds from 260 degrees

From the wind analysis, there are two categories of wind with values for direction 260 degrees, and the following probablilities of occurence in each category.

Category 1: 1 to 9.999 knots with probability of occurence of 6.05% $P_1 := 0.060527$

Category 2: 10 to 19.999 knots with probability of occurence of 1.07% $P_2 := 0.010674$

Category 3: 20 to 29.999 knots with probability of occurence of .0034% $P_3 := .000034$

For the fetch shown in the drawing above, using CEDAS for restricted open water fetches, the wind direction of 250 degrees, a duration of 1 hour, the average wind velocity of 5 knots, we find that a significant wave of height 0.09 foot will be generated with a significant period of 0.69 sec.

With the average wind velocity of 15 knots, we find that a significant wave height of 0.49 feet with the significant wave period of 1.47 sec will be generated.

With the average wind velocity of 25 knots, we find that a significant wave height of 1.11 feet with the significant wave period of 2.15 sec will be generated.

$H_{MO1} := 0.09$ $T_{P1} := 0.69s$

$H_{MO2} := 0.49$ $T_{P2} := 1.47s$

$H_{M03} := 1.11$ $T_{P3} := 2.15s$

The expected number of waves in an hourly wind event:

$$E_1 := \frac{1}{T_{P1}}\cdot 60\frac{sec}{min}\cdot 60\frac{min}{hr} \qquad E_1 = 5.217\times 10^3\,hr^{-1}$$

$$E_2 := \frac{1}{T_{P2}}\cdot 60\frac{sec}{min}\cdot 60\frac{min}{hr} \qquad E_2 = 2.449\times 10^3\,hr^{-1}$$

$$E_3 := \frac{1}{T_{P3}}\cdot 60\frac{sec}{min}\cdot 60\frac{min}{hr} \qquad E_3 = 1.674\times 10^3\,hr^{-1}$$

The general direction of the waves are 299 degrees in both instances and the shorelines most affected will be oriented perpendicular to this direction

$$\theta := [299 - (309 - 180)]deg$$

$$\theta = 170\,deg \qquad \sin(\theta) = 0.174$$

$$m_1 := H_{MO1}{}^2\cdot P_1\cdot 24\cdot 365\frac{hr}{yr}\cdot E_1\cdot\sin(\theta) \qquad m_1 = 3.891\times 10^3\,yr^{-1}$$

$$m_2 := H_{MO2}{}^2 \cdot P_2 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_2 \cdot \sin(\theta) \qquad m_2 = 9.547 \times 10^3\, yr^{-1}$$

$$m_3 := H_{MO3}{}^2 \cdot P_3 \cdot 24 \cdot 365 \frac{hr}{yr} \cdot E_3 \cdot \sin(\theta) \qquad m_3 = 74.9\, yr^{-1}$$

$$E_{260} := m_1 + m_2 + m_3 \qquad E_{260} = 1.351 \times 10^4\, yr^{-1}$$

Calculation of N

A conversion value to convert the max wave height of a wave state to the moment magnitude wave height is 1.8, hence let

$H_{max} := 1$ The design vessel wave height

$$H_{MOV} := \frac{H_{max}}{1.8} \qquad H_{MOV} = 0.556$$

Define V to be the number of vessels "use days" in Glacier Bay per season.

Not every vessel entering Glacier Bay will cause a wake which is incident on Beach A in the above example. Of the 241 total vessel tracks, 36 were counted within 2000 feet of Site 11, Beach A.

$V := \frac{2908}{yr}$ This is the current number of "use days" for permitted vessel entries into Glacier Bay. (refered to as Alternative 1)

$$A := V \cdot \frac{36}{241} \qquad A = 434.39\, yr^{-1} \qquad 15 \cdot A = 6.516 \times 10^3\, yr^{-1}$$

or once every 5 days during the 3 month season.

Using this calculation as the basis for the vessel waves which affect each site assumes that the 241 vessel tracks provided by Glacier Bay National Park represent a statistically significant sampling of all vessels which enter the Bay. In fact, we know this is not the case, since the tracks provided include only tour vessels, charter vessels and cruise ships.

The value of N for the site would then be:

$$N := \frac{H_{MOV}{}^2 \cdot 15 \cdot A}{E_{130} + E_{200} + E_{260}}$$

where the value of 15 represents the number of waves per vessel wake.

$$N = 0.019$$

This is a moderate level of significance for vessel wake potential.

Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants
1506 West 36th Avenue Anchorage, Alaska 99503 (907) 561-1011 Fax (907) 563-4220

Memorandum

To: File — Project No.: 02056.02

From: Jennifer Wilson — Date: October 3, 2002

Re: *CoastWalkers Polygon Table*

Project: Glacier Bay National Park and Preserve Vessel Quotas and Operating Requirements Environmental Impact Statement, Appendix F Technical Memorandum

---

The attached document, *CoastWalkers Polygon Table*, provides a detailed list of the polygons that make up each site as provided in this database. The purpose of this list is to provide an exact location of the beaches studied for the EIS.

CoastWalkers Polygon Table
Listed by Site

Site	CoastWalker Polygons
1	H008
	H009
	H010
	H011
	H012
	H013
	H014
	H015
	H016
	H017
	H018
	H019
	H048
	H049
	H050
	H051
	H052
	H053
	H054
	H055
	H056
2	H096
	H097
	H098
	H099
	H100
3	N120
	Y003
	Y004
	Y005
	Y006
	Y007
	Y008
	Y009
	Y010
	Y011
	Y012
	Y013
	Y014
	Y015
	Y016
	Y017
	Y018
	Y019
	Y020
	Y021

Site	CoastWalker Polygons
	Y022
	Y023
	Y024
	Y025
	Y026
	Y027
	Y028
4	N083
	N084
	N085
	N086
	N087
	N088
	N018
	N019
	N020
	N021
	N022
	N023
	N024
	N025
	N002
	N003
	N004
	N005
	N006
	N007
	N008
5	W001
	W002
	W003
	W004
	W005
	W006
	W007
	W015
	W016
	S083
	S084
	W019
	W020
	W021
	W022
	W023
	W034
	W035

Site	CoastWalker Polygons
	W036
	WO41
	WO42
	WO43
	WO44
	W055
	W056
6	II044
	II045
	II046
	II047
	II048
	II049
	II050
	II051
	II052
	II038
	HH054
	HH055
	HH056
	HH057
	HH058
	HH059
	HH060
	HH061
	HH062
	HH063
	HH049
	HH050
	HH051
	HH052
7	D013
	D014
	D015
	D016
	D017
	D018
	D019
	D020
	D021
	D022
	D023
	D024
	D025
	D026
	D027

CoastWalkers Polygon Table
Listed by Site

Site	CoastWalker Polygons
	D028
	D029
	D030
	D031
	D032
	D033
	D034
	D038
	D039
	D040
	D041
	D042
	D043
	D044
	D045
	D046
	D047
	D048
	D049
	D050
	D051
8	X013
	X014
	X015
	X016
	X017
	X018
	X019
	X020
	X021
	X022
	X023
	X070
	X071
	X072
	X073
	X074
	X075
	X076
	X077
	X078
	X079
	X080
	X081
	X082
	X083

Site	CoastWalker Polygons
	X084
	X085
	X086
	X087
	X088
	X089
	X090
	X091
	X092
	X093
	Z094
	Z095
	Z096
	Z097
	Z098
	Z099
	Z100
	Z101
	Z102
	Z103
	Z104
	Z105
	Z106
	Z107
	Z108
	Z109
	Z110
	Z111
	Z112
	Z113
	Z114
	Z115
	Z116
	Z117
	Z118
	Z119
	Z120
	Z121
	Z122
	Z123
	Z124
	Z125
	Z126
	Z127
	Z128
	Z129

Site	CoastWalker Polygons
	Z130
	Z131
	Z132
	Z133
9	X008
	X009
	X010
	X011
	X012
	X032
	X033
	X034
	X035
	X036
	X037
	X038
	X039
	X040
	X041
	X053
	X054
	X055
	X056
	X057
	X058
	X059
	X060
	X061
10	V038
	V039
	V040
	V041
	V093
	V094
	V095
	V096
	V097
	V098
	V099
	V100
	V101
	V102
	V103
	V104
	V105
11	FF004

CoastWalkers Polygon Table
Listed by Site

Site	CoastWalker Polygons
	FF005
	FF006
	FF007
	FF008
	FF009
	FF053
	FF054
	FF055
	FF056
	FF057
	FF058
	FF059
	FF060
	FF061
	FF062
	FF063
	FF064
	FF065
	FF066
	FF067
	GG001
	GG002
	GG003
	GG004
	GG005
	GG006
	GG007
	GG008
	GG009
	GG010
	GG011
	GG012
	GG013
	GG014
	GG015
	GG016
	GG017
	GG018
	GG019
	GG020
	GG021
	GG022
	GG023
	GG024
	GG025
	GG026

Site	CoastWalker Polygons
	HH001
	HH002
	HH003
	HH004
	HH005
	HH006
	HH007
	HH008
	HH009
	HH010
	HH011
	HH012
	HH013
	HH014
	HH015
	HH016
	HH017
	HH018
	HH019
	HH020
	HH021
	HH022
	HH023
	HH024
	HH025
	HH026
	HH027
12	AA001
	AA002
	AA003
	AA004
	AA005
	AA006
	AA007
	AA008
	AA009
	AA010
	AA011
	AA012
	AA013
	AA014
	AA015
	AA016
	AA017
	AA018
	AA019

Site	CoastWalker Polygons
	AA020
	AA021
	AA022
	AA023
	AA024
	AA025
	AA026
	AA027
	AA028
	AA029
	AA030
	AA031
	AA032
	AA033
	AA034
	AA035
	AA036
	AA037
	AA038
	AA039
	AA040
	AA041
	AA042
	DD001
	DD002
	DD003
	DD004
	DD005
	DD006
	DD007
	V011
13	AA083
	AA084
	AA085
	AA086
	AA087
	AA088
	AA089
	AA090
	AA091
	AA092
	AA093
	AA094
	AA095
	AA096
	AA097

CoastWalkers Polygon Table
Listed by Site

Site	CoastWalker Polygons
	AA098
	AA099
	AA100
	AA101
	AA102
	AA103
	AA104
	AA109
	AA110
	CC146
14	CC078
	CC079
	CC080
	CC081
	CC082
	CC083
	CC084
	CC085
	CC086
	CC087
	CC088
	CC089
	CC090
	CC091
	CC092
	CC093
	CC094
	CC095
	CC073
	DD073
	DD074
	DD075
	DD076
	DD077
	DD078
	DD079
	DD080
15	CC117
	CC118
	CC119
	CC120
	CC121
	CC122
	CC123
	CC124
	CC125

Site	CoastWalker Polygons
	CC126
	CC127
	CC128
	CC129
	CC130
16	AA149
	AA150
	AA151
	AA152
	AA153
	AA154
	AA155
	AA160
	AA161
	AA162
	AA163
	BB068
	BB069
	BB070
	BB071
	BB072
	BB073
17	BB082
	BB083
	BB084
	BB085
	BB086
18	BB091
	BB092
	BB093
	BB094
	BB095
	BB096
	BB097
	BB098
	BB099
	BB100
	BB103
	BB104
	BB105
	BB106
	BB107
	BB108
	BB109
	BB110
	BB111

Site	CoastWalker Polygons
	BB112
	BB113
	BB114
	BB115
	BB116
	BB117
	BB118
	BB119
	BB120
	BB121
	BB122
	BB123
	BB124
	BB125
	BB126
	BB127
	BB128
	BB129
	BB130
	BB131
	BB132
	BB133
	BB134
	BB135
	BB136
	BB137
	BB138
	BB139
	BB140
	BB141
	BB142
	BB143
	BB144
	BB145
	BB146
	BB147
	BB148
19	NO POLYGONS - Upper Muir Inlet north of McConnel Ridge
20	NN073
	NN074
	OO67

CoastWalkers Polygon Table
Listed by Site

Site	CoastWalker Polygons
	OO68
	OO69
	OO70
	OO71
	OO72
	OO73
	OO74
	OO75
	OO76
	OO77
	OO78
	OO79
	OO80
	OO83
	OO84
	OO085
	OO086
	OO087
	OO088
	OO089
	OO090
	OO091
	OO092
	OO093
	OO094
	OO095
21	NO POLYGONS - Upper end of Muir Inlet
22	NO POLYGONS - South Marble Island